VSB – Technical University of Ostrava
Faculty of Electrical Engineering and Computer Science

Design of the LV protection relay testing panel

MASTER THESIS

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VSB TECHNICAL UNIVERSITY OF OSTRAVA | FACULTY OF ELECTRICAL ENGINEERING AND COMPUTER SCIENCE

Design of the LV protection relay testing panel

Návrh testovacího panelu pro ochrany nízkého napětí

Anton Sokolov

Master diploma thesis

Supervisor: Ing. Tadeusz Sikora, Ph.D.

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Faculty of Electrical Engineering and Computer Science
Department of Electrical Power Engineering

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- Introduction to LV electrical motors, control and protection of motors
- UMC100 as a motor controller, its components and connection
- UMC100 control and protection functions
- UMC100 communication interface
- Practical testing application configuring for UMC100
- Tests and measurements of UMC100 application functions
- Conclusion. Advantages and disadvantages of UMC100

References:

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2) Baurand, G., Moliton, V., The protection of LV motors, Schneider Electric, Cahier Technique no. 211, 2007
3) UMC100.3 Universal Motor Controller Technical Description, ABB, 2016
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5) Müller P.O. et al., Intelligent motor control, ABB, 2010

Extent and terms of a thesis are specified in directions for its elaboration that are opened to the public on the web sites of the faculty.

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Declaration made by the student

I hereby confirm the submission of the digital version of my thesis. I declare that I have written this thesis independently. I have listed all the literary sources and publications from which I have drawn my knowledge.

Date:_____________ Signature:_____________

Abstrakt

Tato práce představuje teoretický popis a praktické provedení řešení ochrany a řízení asynchronních motorů NN s využitím zařízení ABB UMC100 – komplexního ovladače motoru.

Teoretická část diplomové práce obsahuje popis nejčastějších poruch motoru, které je třeba řešit, dále obsahuje různé možné způsoby ovládání a spouštění motoru a jejich výhody a také informace o samotném zařízení UMC100 , jeho prvky a funkce.

Praktická část ukazuje demo panel sestavy pro ochranu a řízení motoru, její strukturu a parametrizaci, testy a měření funkcí a parametrů panelu.

Klíčová slova

UMC100, LV indukční motor, ochrana motoru, ovládání motoru, správa motoru, ochranný demo panel, ochranné relé.

Abstract

This thesis represents the theoretical description and practical implementation of the LV asynchronous motor protection and control solution with the usage of ABB UMC100 device – a comprehensive motor controller.

The theoretical part of the diploma thesis contains the description of the most common faults happening to the motor which must be resolved, it also contains the different possible ways to control and start the motor and their advantages, as well as information about the UMC100 device itself, its elements and functions.

The practical part shows the demo panel assembly for motor protection and control, its structure and parametrization, tests and measurements of the panel functions and parameters.

Keywords

UMC100, LV induction motor, motor protection, motor control, motor management, protection demo panel, protective relaying.

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List of symbols and abbreviations used

ABB – Asea Brown Boveri;
AC – Alternating Current;
AI – Alternative Input;
AO – Alternative output;
CT – Current transformer;
DC – Direct current;
DCS – Distributed Control System;
DI – Digital Input;
DO – Digital Output;
DOL – Direct Online;
EOL – Electronic Overload;
GF – Ground Fault;
IEC – International Electrotechnical Commission;
IED – Intelligent electronic device;
IO – Input-Output;
LED – Light-Emitting Diode;
LV – Low Voltage;
LCD – Liquid Crystal Display;
MCB – Miniature Circuit Breaker;
NO – Normally Open;
NC – Normally Closed;
PC – Personal Computer;
PLC – Programmable Logic Controller;
PTC – Positive Temperature Coefficient ;
SC – Short-Circuit;
THD – Total Harmonic Distortion;
TOL – Thermal Overload;
UC – Universal Current
UMC – Universal Motor Controller;
USB – Universal Serial Bus;
VFD – Variable Frequency Drive.

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Introduction

This work is devoted to the description of research work and practical tests of real application functions in the field of low voltage motor protection and control using UMC100 as a comprehensive motor protection and control device.

The first chapter contains information about the most common faults in the motor applications and their possible aftermaths to be resolved and prevented by the protection means, as well as the information about required control starting functions depending on the application requirements.

The second chapter is devoted to a basic overview of the main components and functions of the UMC100 device as a motor controller.

The third chapter describes the theoretical background and configuration of the UMC100 motor protection functions.

The fourth chapter represents the UMC100 available control functions, possible ways to configure and use them.

The fifth chapter shows the real LV motor control and protection demo panel assembly, its wiring, and parametrization for demonstration purposes.

The sixth chapter contains the testing results and measurements of demo panel functions.

1 LV electrical motors, control and protection requirements of motors

The electrical motors must be manufactured in a way to correspond to special operating conditions and cannot be operated without them because of the damage risks to the motor and the environment. To eliminate and reduce these risks, protection devices are used.

Exceeding the operating limits of the motor leads to the disruption of the motor and the mechanisms driven by it, causing interruptions and production losses. The mechanism that converts electrical energy into mechanical can be the place of failure caused by electrical or mechanical reasons. Electrical: overvoltage, voltage drop, unbalance, phase loss, short circuits where the current exceeds disruptive levels; Mechanical: rotor stall, overload causing increased current by the motor and leading to windings overheating. The economic price of these failures can be high. Such failures can also lead to a negative result for the safety of people in a contact with the motor.

To avoid such failures, reduce the consequences, and prevent damage to the power equipment and interruptions in the power supply, protective systems are intended. They protect equipment and isolate it by breaking devices due to the determination of changes in electrical values (voltage, current). Special devices are used to ensure the protection: fuses, circuit breakers, overload relays, combination devices with a bunch of different protection functions.

Nowadays, intelligent electronic devices are most often used in industrial applications to accomplish functions of protection, monitoring, and control of induction motors. These IEDs properly simulate the thermal characteristic of the motor. They also afford a few control functions to reduce wiring and operate the complex auto / manual logic in a system with multiple control systems.

1.1 Causes of the motor faults and their consequences

To select the motor protection device and its parameters, it is extremely important to be acknowledged of motor fault types and how they affect the motor.

In an application with motors, we can differ a few fault types: faults occurring internally in the motor, and faults occurring externally.

Internal faults: SC between conductor and ground, SC between conductors, SC in coils, overheating of winding, bar breaking in a squirrel cage motors, problems with the bearings.

External faults: The origin of these faults is outside of the motor, but they can lead to damage to the motor. The reasons for such faults: power source (power cuts, phase reversal or unbalance, undervoltage, overvoltage), the operating mode of the motor (overload operation, the excessive number of starts and the starting operations, the load inertia), the installation of the motor (misalignment, unbalance, excessive stresses on the shaft)

1.1.1 Internal faults in the motor

The stator winding comprises copper conductors covered with varnish insulation. Disruption of the insulation might lead to a phase-to-ground SC, SC between few phases, or between the coils in a phase.

The different factors could cause faults such as electrical (surface discharge, overvoltage), thermal (overheating), mechanical (vibration, electrodynamic stresses on the conductors), aging, breaking and deterioration of insulation, presence of conductive deposits (dust, moisture, etc.), errors in wiring and starts during service or maintenance conditions.

An SC is defined by a rapid current rise, which can become a hundred times greater than the nominal current in a short period. An SC leads to disruptive effects and causes huge damages to the equipment. It is characterized by two factors: thermal factor – released energy in the electrical circuit during SC which leads to melting of contacts of the contactor, destruction of bimetallic elements, generation of arc, burning of insulation; and electrodynamic factor - mechanical forces between the conductors produced by peak currents which lead to deformations of conductors, insulation breakage, repulsion of contactor's contacts.

The most frequent cause of disruptions in the windings is high temperature overheating. The overload leads to a current increasing in the windings which causes overheating.

The dependence of winding insulation resistance on its temperature is shown in Figure 1: the insulation resistance reduces as the temperature increases. Consequently, the life of the windings and motor itself degrades.

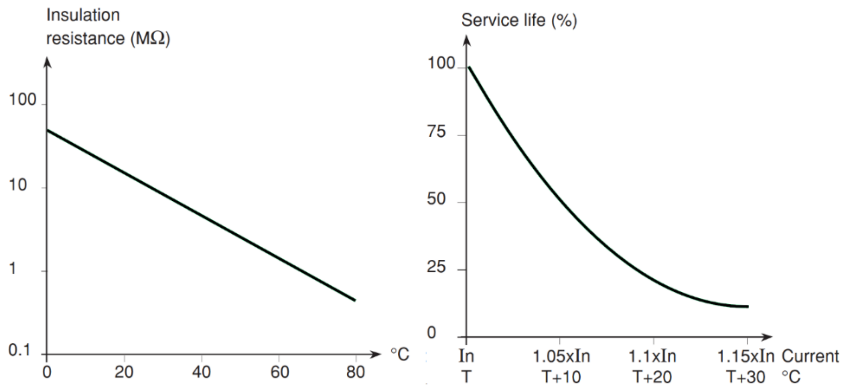

Figure 1 - Windings insulation resistance and service life of a motor as a function of operating temperature and current consumption [2]

1.1.2 Faults external to the motor

Overvoltage

An overvoltage is a kind of voltage supplied to the device where the peak value oversteps the limits of a standard range. Overvoltage type could have a various nature: lightning strikes, electrostatic discharges, management of devices connected to the same grid. These interferences, which are superposed on the network voltage, can affect in two ways: between the phase and the ground and between the different phases. The high voltage leads to the saturation of the motor core which increases the line currents. The overvoltage causes a dielectric breakdown in the motor windings, reduction of insulation life, or insulation failure, which disrupts the motor.

Undervoltage

An undervoltage situation could be caused by problems with the power source and leads to the higher current consumption of the motor in terms to keep the generated power and torque at the same level to be able to handle the load. Continuous operation of motors at low voltage can cause overheating.

Phase unbalance

Phase unbalance means that the magnitudes of voltage in different phases are not the same or the phase angle difference is not 120°. Even a relatively small phase voltage unbalance (caused by source properties, asymmetrical load, contacts and terminals corrosion, and wearing) could result in large negative-sequence current due to fact that the negative sequence reactance of the motor is sufficiently lower than the positive sequence reactance. This leads to the temperature increase. Additionally, the rotor is heated due to the double frequency of the negative sequence currents, which generates a double speed rotated field in the opposite direction to the rotor. In some cases, it is more efficient to measure current imbalance rather than voltage imbalance because it can be caused by the faults between stator turns, loose connections, etc.

IEC 60034-26 [5] contains a graph of the motor derating depending on voltage unbalance (factors deviation) which is shown in Figure 2. The voltage unbalance here could be calculated as follow:

$$U_{unb} = MAX(\frac{U_{\max} - U_{mean}}{U_{mean}}; \frac{U_{mean} - U_{\min}}{U_{mean}}) \quad (1)$$

where

U_{unb} – voltage unbalance, p.u.;

$U_{\max}$ – maximum phase voltage, V;

$U_{\min}$ – minimum phase voltage, V;

U_{mean} – mean phase voltage, V.

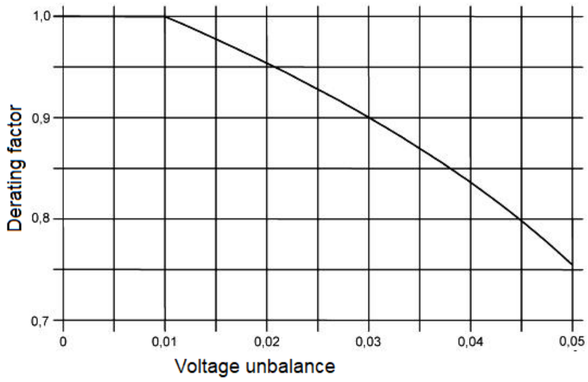

Figure 2 – Motor derating factor dependence on the voltage unbalance [5]

Phase loss

If the motor is energized and one of the supply phases is open (due to burned fuse, loose cable) the motor will not start, but the stator winding will overheat rapidly and could be destroyed. If the motor is running and the load is close to the nominal torque when phase loss occurred, the motor will stall, but if the motor still rotating, there will be extra losses and damage of cables and motor windings caused by the rapid increase of current in the remaining phases.

Voltage dip

A voltage dip is a sudden voltage drop at a grid node resulting in a voltage level of 1-90% of the rated voltage in the LV grid. A power cut is an event of a brownout when the voltage drop can be more than 99%

The voltage drop might be caused by various factors outside the considering equipment (a fault in the main network or a short circuit) or by a factor related to the installation itself (high power loads - motors, transformers). Such voltage changes can strongly affect the motor.

When a voltage dip happens to an induction motor, the torque reduces suddenly and causes a slowdown. When the torque generated by the motor is less than the load torque, the motor stalls. Then the recovery of the power process requires the reacceleration current. If there are many motors in the application, their simultaneous reacceleration leads to a voltage drop in the network. This can cause hard reacceleration (long recovery and overheating) and even unsuccessful (when the generated torque is less than the load torque).

A reclosing of the induction motor could happen in a phase difference of 180° between the network voltage and the residual voltage of the motor. Then the amplitude of this current peak could be several times greater than the starting current. Such overcurrents and the consequent voltage drops could lead to different effects: overheating and electrodynamic forces in the windings which disrupt the insulation, bring heavy mechanical stresses. They could make an influence on contactors (melting and welding) or cause the operation of the protections of the application and stop a process.

Presence of harmonics

Non-linear loads can cause the parasite harmonics in current and voltage. The total harmonic distortion rate can be calculated as follows:

$$THD(\%) = 100 \cdot \sqrt{\sum_{h=2}^{\infty} (\frac{Y_h}{Y_1})^2} \quad (2)$$

where

Y_h – amplitude of h-order harmonic;

Y_1 – amplitude of 50 Hz component.

A harmonic distortion is a form of interference in the network that can reduce energy quality at a level of more than 5%. Electronic power devices could generate harmonics into the network. The motor can also generate harmonics of the 3rd order. Harmonics lead to a rise of the eddy currents in the core, causing overheating and insulation damage, also produce pulsating torques (leading to vibration and mechanical disruptions), and limit the level of the load which the motor could bear.

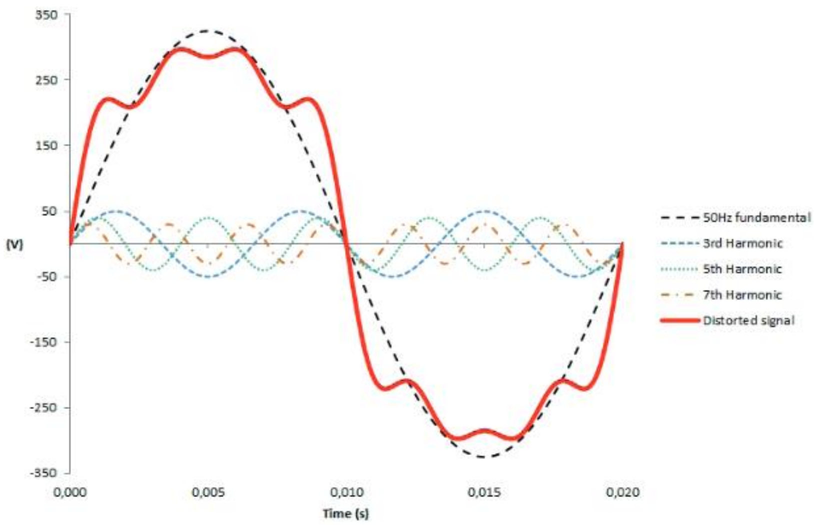

Figure 3 – Decomposition of the signal with harmonics [6]

Motor start: long start and frequent starts

The starting time of the motor is the time which the motor needs to achieve its rated rotation speed. The starting time depends on the resistive load torque and the motor-generated torque. A rise in the resistive torque caused by a load together with a reduction in the motor torque caused by a voltage drop leads to the motor starting time increasing as follows:

$$t_s = \frac{\pi}{30} \cdot J \cdot \frac{N}{T_m - T_r} \tag{3}$$

where

J – moment of inertia of the motor, kgm²

T_r – resistive torque, Nm

T_m – motor torque, Nm

A high starting current is not allowed for a period longer than the normal starting time to prevent overheating. Also, each motor can hold only a limited number of starts per a certain period of time. Besides, every motor has a maximum starting time that depends on the starting current (Fig. 4).

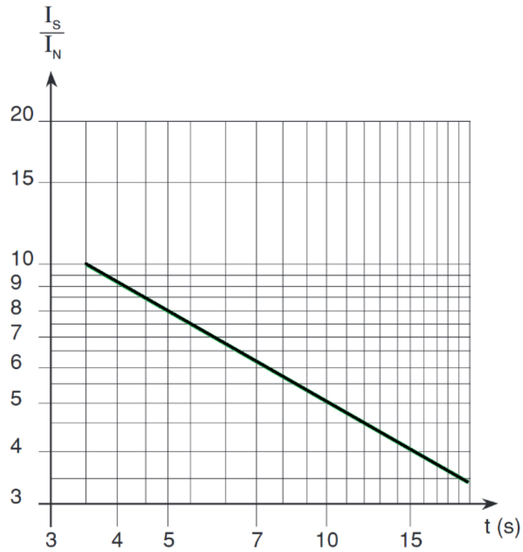

Figure 4 – Permissible stating time dependence on starting and rated currents ratio [2]

Locked rotor

Mechanical issues can cause locking of a rotor which produces a high overcurrent equal to the starting current. But the overheating level is much greater in this case due to the high level of rotor losses and the inability of ventilation since it depends on the rotation of the rotor. Thus, the temperature of the motor could reach very high values. When the motor is locked, the rotational speed n=0 and the slip s=1. And the inrush current is equal:

$$I_{1z} = I_2^{'} = \frac{U_1}{\sqrt{(R_1 + R_2^{'})^2 + (X_{r1} + X^{'}_{r20})^2}} \tag{4}$$

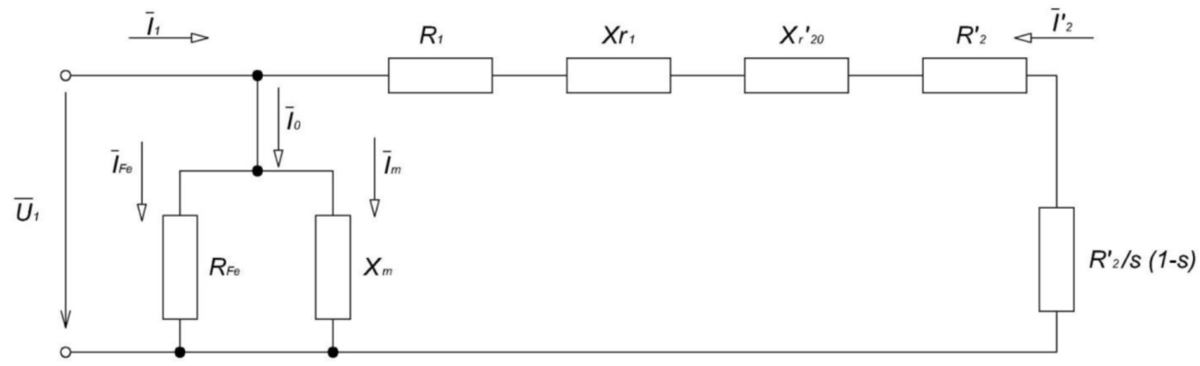

Figure 5 – Circuit model of the asynchronous motor

where

U_1 – primary input voltage, V

R_1 – Stator winding resistance, Ω

X_{r1} – Reactance of stator coil, Ω

X'_{r20} – Rotor circuit reactance, converted to the stator parameters, Ω

R_2' / s – Total active resistance of rotor circuit, converted to stator parameters, Ω

X_m – Reactance of the magnetic circuit, Ω

R_{Fe} – Resistance of the magnetic circuit, Ω

I_{1z} – Stator current, A.

Overload (deceleration or overspeed)

An increase in the resistive torque or the network voltage drop (> 10% Un) can lead to motor overload. The high current consumed by the motor leads to overheating which decreases the life of the equipment and might be fatal. The temperature rise is proportional to the square of the current multiplied by the time.

1.2 Induction motor starting and its methods

Motors have a high peak current during the starting period because this condition corresponds to a short circuit experiment with a slip equal to 1. The start condition when the high peak current flows in the stator winding produces a very intense electromagnetic field in the stator. This field generates an induced voltage and current of high values in the rotor, causing a strong electromagnetic field in it. Such intense fields produce sufficient rotational torque so the motor can withstand the load torque and start to accelerate.

The starting peak current reduction also reduces the generated starting torque, so we must be sure that generated torque is enough to start the motor to avoid stalling of the rotor (locked rotor condition). Types of motor starting systems:

1.2.1 Direct Online starter

This method is simple, the supply voltage is applied directly to the motor. It results in a high value of the peak current, approximately 3-7 times the nominal current, and the starting torque is 1.5-2.5 times more than the load torque. The direct starter consists of a circuit breaker and a coil operated contactor with start and stop pushbuttons. This method is used mostly for small motors up to 5 kW ib order to avoid voltage drops in the grid because of the high starting current, which can thermally and electrodynamically disrupt the motor windings.

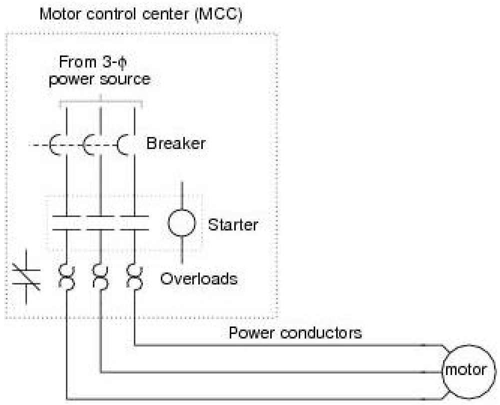

Figure 6 – Direct online starter connection [13]

1.2.2 Star-delta starter

It is a method to decrease a peak current by the mean of stator impedance increasing. It is used for the cage motors which are designed to work in steady-state conditions with delta connected stator winding. During starting, the stator winding is star-connected to reduce the voltage by $\sqrt{3}$ times compared to delta connection conditions and consequently reduce the starting current and starting torque by 3 times.

Starting phase and line current in Y connection:

$$I_{st.Y.ph} = I_{st.Y.l} = \frac{U_{ph}}{Z_{ph}} = \frac{U_l}{\sqrt{3} \cdot Z_{ph}} \tag{5}$$

Starting phase and line currents in D connection:

$$I_{st.D.ph} = \frac{U_l}{Z_{ph}} \tag{6}$$

$$I_{st.D.l} = \sqrt{3} \cdot I_{st.D.ph} = \frac{\sqrt{3} \cdot U_l}{Z_{ph}} \tag{7}$$

So, the line current difference in Y and D connection:

$$\frac{I_{st.Y.l}}{I_{st.D.l}} = \frac{U_l}{\sqrt{3} \cdot Z_{ph}} : \frac{\sqrt{3} \cdot U_l}{Z_{ph}} = \frac{1}{3} \tag{8}$$

Also, the torque difference ($T \propto U^2$):

$$\frac{T_{st.Y.l}}{T_{st.D.l}} = \frac{\left(\frac{U_l}{\sqrt{3}}\right)^2}{U_l^2} = \frac{1}{3} \tag{9}$$

where

$I_{st.Y.ph}$, $I_{st.Y.l}$ – starting phase and line currents for Y – connection, A

$I_{st.D.ph}$, $I_{st.D.l}$ – starting phase and line currents for D – connection, A

$T_{st.Y.l}$, $T_{st.D.l}$ – starting torque for Y and D – connections, Nm.

U_{ph}, U_l – phase and line voltages, V

Z_{ph} – phase impedance of the motor, Ω

When the motor is accelerated up to about 80% of its nominal speed and the current is decreased, the starter is switched to the delta connection of the stator windings.

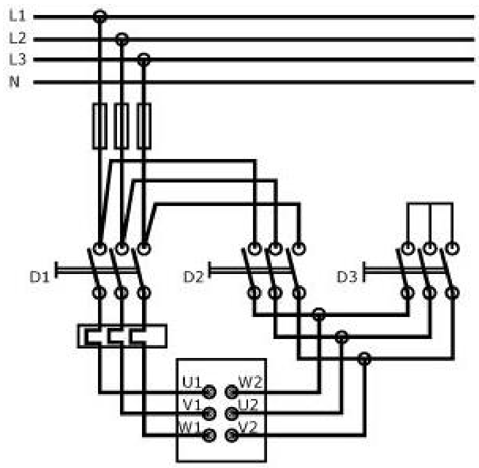

Figure 7 – Star-Delta starter connection [13]

1.2.3 Autotransformer starter

It is operated by a two-position switch using a timer to switch start/run positions. This type of starter is just a three-phase transformer with several taps, which allows starting the motor at different voltage levels (let's say 50-65-80% of full voltage). Reducing the voltage leads to the proportional motor current reduction by the transformer ratio coefficient, and torque reduces by the squared transformation factor. In this application, the current flowing from the network is less than the motor current by the transformation ratio factor (and less than current for DOL start by the squared transformer ratio coefficient).

Current during DOL starter:

$$I_{st.DOL} = \frac{U_{network}}{Z} \tag{10}$$

Motor current during auto-transformer starter:

$$I_{st.AT.motor} = \frac{U_{network}}{p \cdot Z} = \frac{I_{st.DOL}}{p} \tag{11}$$

Network current during auto-transformer starter:

$$I_{st.AT.network} = \frac{I_{st.AT.motor}}{p} = \frac{I_{st.DOL}}{p^2} \tag{12}$$

Torque during auto-transformer starter ($T \propto U^2$):

$$\frac{T_{st.AT}}{T_{st.DOL}} = \frac{\left(\frac{U_{network}}{p}\right)^2}{U_{network}^2} = \frac{1}{p^2} \tag{13}$$

where

$I_{st.DOL}$ – starting current in case of DOL starter, A

$I_{st.AT.motor}$, $I_{st.AT.network}$ – starting current of motor and network in case of auto-transformer starter, A

$T_{st.DOL}$, $T_{st.AT}$ – torque in case of DOL and autotransformer starter, Nm

p - transformation ratio

Initially, the switch is in the "start" position, and a decreased voltage (corresponding to the selected tap) is supplied to the stator winding. When the motor accelerates to 80% of the nominal speed, the transformer is automatically switched off because of switching from „start“ to „run“ position.

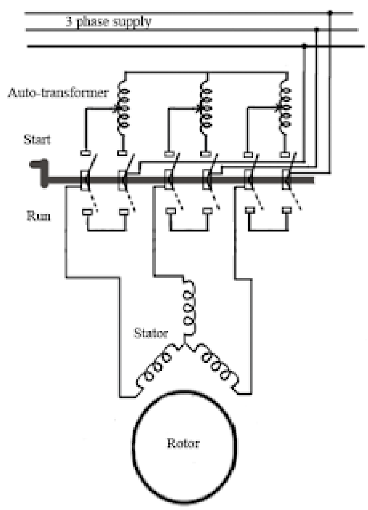

Figure 8 – Autotransformer connection [14]

1.2.4 Soft starter system

This method is intended to gradual voltage level increase across the terminals for the motor starting, providing a controlled acceleration to rated speed. The voltage limitation decreases starting current peak and starting torque, reducing mechanical stress. This application requires 3 pairs of thyristors (1 per phase) that gradually limit the voltage supplied to the terminals. The current reduction is proportional to the voltage reduction. The torque is proportional to the square of the voltage, in that case even a little voltage reduction makes a sufficient torque reduction. When the motor reaches nominal speed, the soft starter is shunted, and the motor is connected across the line to full power. The soft starter generates almost no harmonics and it has great efficiency.

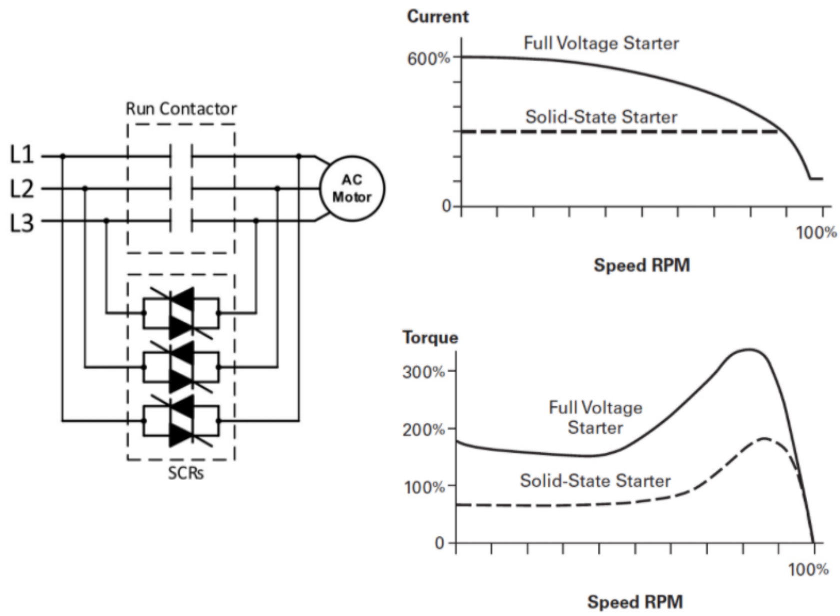

Figure 9 – Soft starter connection and graphs of current and torque during acceleration [15]

1.2.5 Frequency converter (Variable frequency/speed drive)

A VFD can provide the same start control functions as the soft starter, but by changing the frequency rather than the magnitude of voltage directly. This type of converter consists of two parts, the first one transforms AC network energy to DC (rectifier) and the second one transforms this DC energy to AC with a variable frequency of 0-250 Hz (inverter). The rotational speed is proportional to the frequency, so it is possible to regulate the rotational speed by adjusting the converter frequency and this is a big advantage for a continuous run because VFD could be used not only for start but also for continuous operation.

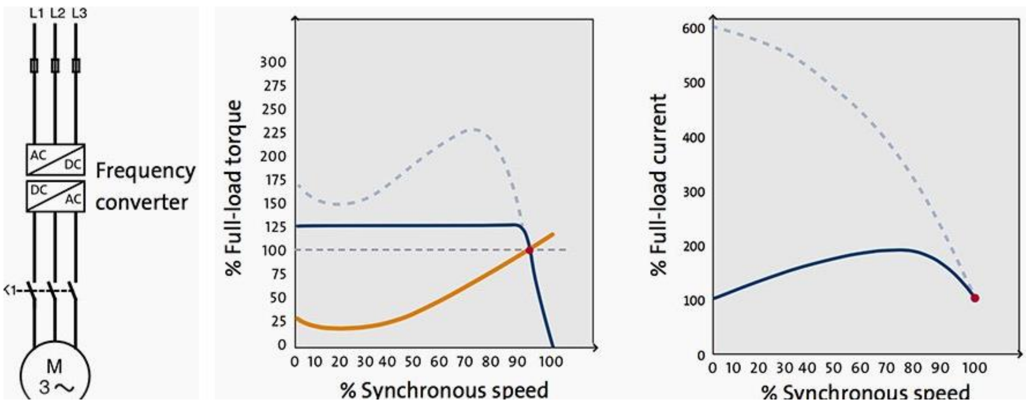

Figure 10 – VFD connection and graphs of current and torque during acceleration [16]

2 UMC100 as a motor controller, its components and connection

The UMC100 device by ABB company has been selected as a protection and control device for theoretical and practical research in the field of LV motor management. So, for the proper usage of this device, it is extremely important to get familiar with its functions and components.

2.1 UMC 100 basic description

The Universal Motor Controller is an intelligent flexible, modular and expandable motor management device for constant-speed, low-voltage asynchronous motors up to 1000 VAC and contains comprehensive motor protection and motor control functions, also fault diagnostic, fieldbus, and Ethernet communication. UMC provides a lot of helpful data without delay, so it is an efficient data source for predictive maintenance. UMC functions could be adapted for many various purposes. This device works independently and protects the motor all the time, even during failure of the control system. The high accuracy of the measurement system allows the most efficient usage of motors and ensures reliable protection tripping.

UMC100 protection functions

The UMC 100 contains the following protection functions: phase failure detection, protection for stalled motors during starting and steady-state operation, overload protection (5E, 10E, 20E, 30E, and 40E), PTC/PT100/PT1000 thermal protection, ground fault protection, voltage and power based protections, harmonic distortion supervision (network quality). The analog inputs are intended for standard signals (0-10 V, 0-20 mA). The device operates in the current range of 0.24-63A (For higher currents the additional current transformer is required).

UMC100 control functions

For control functions, UMC100 has DIs and DOs. Also, for increasing the number of inputs and outputs the expansion modules are used. Standard control functions are transparent control, checkback monitoring, direct starter, reversing starter, Y-D starter, actuator, soft starter, pole-changing starter, etc. DIs could be adjusted in different ways to the application requirements. The internal control function logic can be changed for various purposes. The operator can control the device in different ways (LCD panel, DI, DCS)

Communication interface

The UMC100 can be connected to various fieldbus networks – PROFIBUS, PROFINET IO, DeviceNet, MODBUS, MODBUS TCP and all the data from the device could be received via the fieldbus. But it is possible to use UMC100 as an autonomous device and do not connect it to the fieldbus network. Even in the case of the bus failure the protection and control functions are still operating

2.2 Elements, components, and technical parameters of UMC100

The operating elements of UMC100 DC and UC versions are shown in Figure 11 and their technical parameters are shown in Table 1.

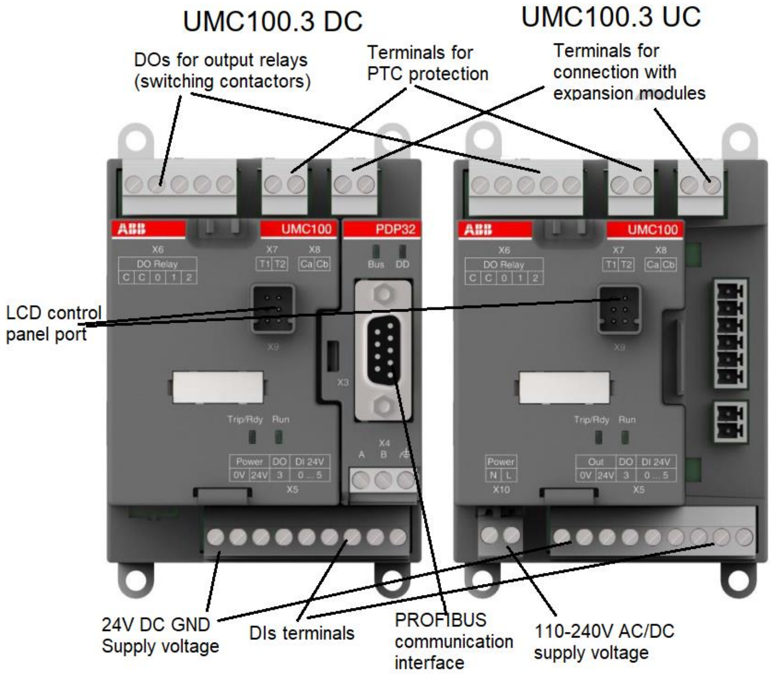

Figure 11 – Operating elements of UMC100

Table 1 – Technical parameters of UMC100 [4]

Parameter	UMC100.3 DC	UMC100.3 UC
Maximum operating voltage	1000 V 50-60 HZ	
Maximum impulse voltage	8 kV	
Power supply	24 VDC (-30..+20%)	110..240 VAC (-15..+10%)
Digital inputs	6x24VDC (6mA consumption)	
Digital outputs	24VDC, max 250 mA	
Relay outputs (DO Relay)	3x12..250V AC/DC, 50000/100000 operations (1A/0.5A)	
Current measurement	0.24..63A (3 phases); 0.24..20 (1 phase) (3% accuracy in range 500..200%, Ie>0.5A)	
Measurement with external CT	60..850A (accuracy 4% in range 50..200% Ie>0.5A)	

The main function blocks and signal paths are shown in Figure 12. Signals from the different protection functions are estimated by the trip unit. A trip or warning signal could be achieved, it depends on the properties. The protection has priority to manage the relay outputs. When the protection is triggered, the required contact opens and the motor stops. Even if the device has a failure, the watchdog opens the relay contacts for safety reasons.

Protection functions: Current measurement is used in the motor model to calculate the corresponding temperature for overload when the threshold level is exceeded, and also for other current-based protections. The PTC thermistor resistance measurement is used to make a difference between hot and cold conditions of the motor.

Control functions: Command signals from LCD panel/DI/DCS are analyzed at the control place selection block according to the application settings, and after that directed to the starter function. The starter function block operates the relay digital outputs according to the input signals and the valid state of the object. Also, some monitoring signals are intended for LCD, LEDs, and communication interface. It is possible to change the logic enclosed in there, but mostly predefined functions are comprehensive.

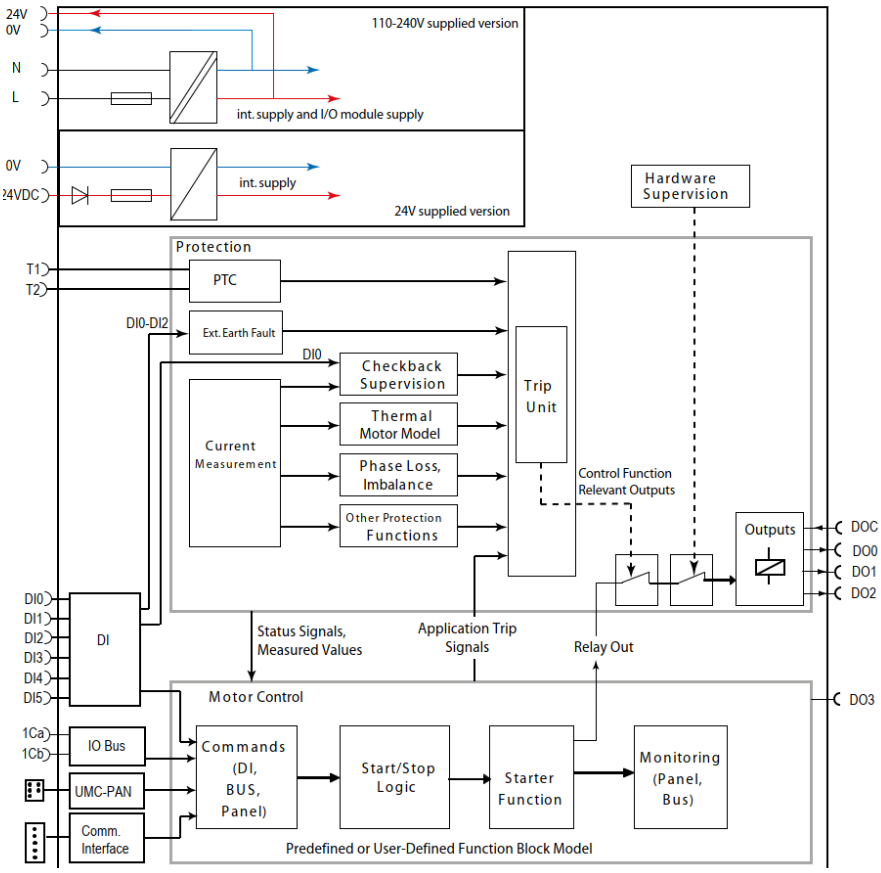

Figure 12 – Function blocks of UMC100 [3]

2.3 Expansion modules and tools for UMC100

Expansion modules allow to extend the number of inputs and outputs. Four modules can be connected to the UMC100 together as maximum: one digital IO module, one voltage module, two analog input modules. The required voltage for all expansion modules is 24VDC; The 110-240V AC/DC type of the UMC provides a 24V DC output for the expansion modules supplying.

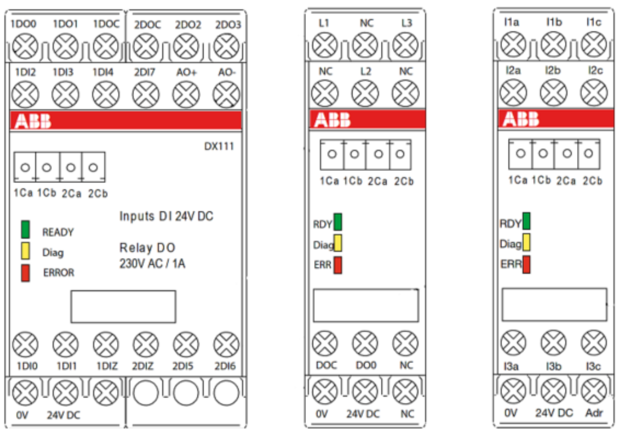

Figure 13 – DX111, VI155, and AI111 expansion modules [3]

Digital IO module DX1xx

The DX1xx is an IO extension device, it provides extra DIs, Dos, and one AO to operate an analog instrument. For inputs 1DI0 to 2DI5 there are next extra options: 1) All of them can detect a fault independently with the unique error code and message. 2) A fault could be deleted as far as the cause of the fault is eliminated or a reset can be performed manually. 3) These inputs could be delayed. The

AO could be used to operate an analogue instrument (shows the motor current), modes are 4-20mA, 0-20mA, 0-10V. The basic parameters of DX1xx modules are listed in Table 2.

Table 2 - Basic parameters of DX1xx modules [4]

Parameters	DX111	DX122
DIs	8 DIs 24 VDC (6 mA)	8 DIs 110-230 VDC (10 mA)
DOs	4x12-250V AC/DC	4x12-250V AC/DC
AO	1 AO	1 AO
Supply voltage	24 VDC	110-240 VAC
Supply current consumption	125 mA	125 mA
Logical 0	-31,2...+5 VDC	0... 40 V AC
Logical 1	+15...+31,2 VDC	74... 265 V AC

Voltage module VI15x

The voltage modules VI15x are used for voltage measurement and provide voltage and power protection functions for the UMC100. It also contains one DO. They could be used in both three-phase or single-phase modes. The V150 version is used only in grounded networks, the V155 could be used also in ungrounded networks.

Table 3 - Basic parameters of VI15x modules [4]

Parameters	VI150	VI155
Supply voltage	24 VDC	
Current consumption	40 mA	55 mA
Voltage input	3ph – 150..690 VAC, 1ph – 90-400VAC	
Electrical grids	TN	TN+TT+TI
Relay output	1x12..250V AC/DC; 50000/100000 cycles (1A/0.5A)	

Analog input module AI111

This module adds 3 AI to the UMC100 which could be used either as temperature inputs (PTC/PT100/PT1000) or as signal inputs (0-10V, 0-20mA). Two analog input modules could be connected to the UMC simultaneously.

LCD panel UMC100-PAN

The UMC100-PAN is used for status monitoring, controlling, and parameterization of UMC. Its main properties: 1) The ability to start and stop the motor; 2) Information about faults; 3) Displaying measured analog and digital values; 3) Parameterization and settings; 3) Downloading and uploading information. It could be connected to a PC via a micro USB interface.

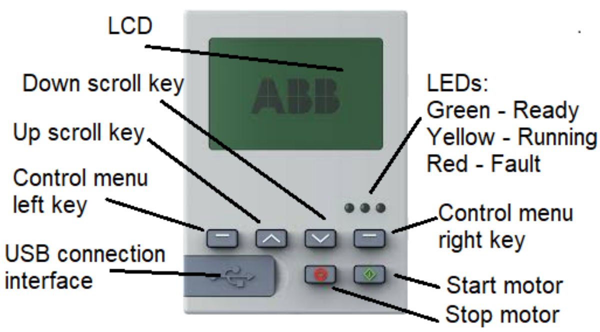

Figure 14 – UMC100-PAN module

3 Configuration and types of the UMC100 protection functions

The list of UMC100 protection functions depends on the presence of voltage module VI15x and analog input module AI111, as well as some external detection devices. Voltage and power-based protection functions require a voltage module, extra temperature supervision functions available with an analog input module.

3.1 Current-based protections

The block diagram for current-based protections is shown in Figure 15, a description is listed below.

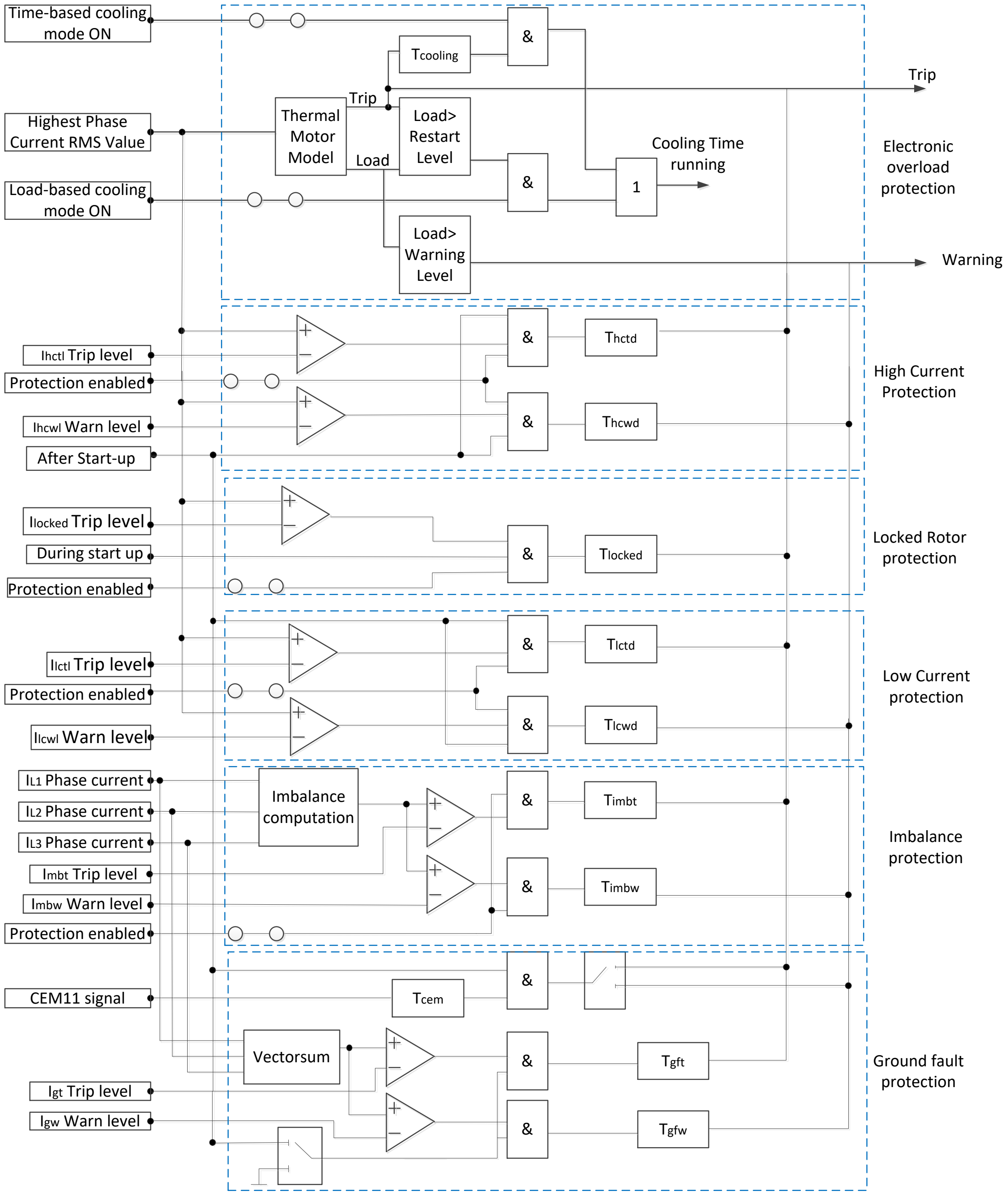

Figure 15 – Block diagram for current based protections

The protections can be configured in the way to trigger a trip or warning, also an operational delay can be adjusted. Some protections are active only after the start, others could be active only during the starting process or always, but faults could not be detected before the motor start. The starting time is considered as being over when the stator current falls below 135% of the nominal current or in case if its class time is over (Table 4)

Table 4 – Class-depending starting time.

Trip class	5E	10E	20E	30E	40E
Start time	1.5s	3s	6s	9s	12s

3.1.1 Electronic overload protection

The current-dependent overload protection of the LV motor evaluates a heating model (considering iron and copper parts) by measuring the motor currents that rise in case of overload and evaluates motor temperature from the calculation. During overload, the temperature and thermal capacity increased forcing the protection to trip when the thermal capacity reaches 100%. This type of protection is used to prevent overheating and, as a result, reduction of the service life and aging of insulation. But it should ensure the continuity of operation by avoiding excessive stoppages of motors, enabling restarting, and allowing the temporary overload during normal start up. The overload curve considers motor heating during a stall, acceleration and overload controlling the thermal capacity when the equivalent motor heating current greater than full load current.

This type of protection is active always and could trigger a trip or a warning. There exists an auto fault reset for the trip function. The overload protection is a time-dependent (inverse) protection. The tripping class for the UMC100 according to IEC 60947-4-1 [11] can be set 5,10,20,30 and 40 (equal to the tripping time in seconds when the actual current is 6 times the nominal current). Class 5 is used for very fast tripping, class 10 is used for artificially cooled motors with low thermal capacity, class 20 is used for general applications, class 30 is intended for high inertial loads to prevent false tripping. It is possible to know the actual thermal capacity used and the predicted time to trip (and time to restart) for the user.

Two ways are used to determine the cooling time for the UMC100 (time to start over the motor after overload trip): 1) Fixed cooling time, which has to be set according to the size and power of the motor, ventilation and cooling type, ambient temperature; 2) Thermal capacity based cooling, a restart could be held when the thermal load value drops under threshold level adjusted by a user. The second option is better to use for a cyclic start-stop operation to keep cycles long and allow the motor to cool down sufficiently.

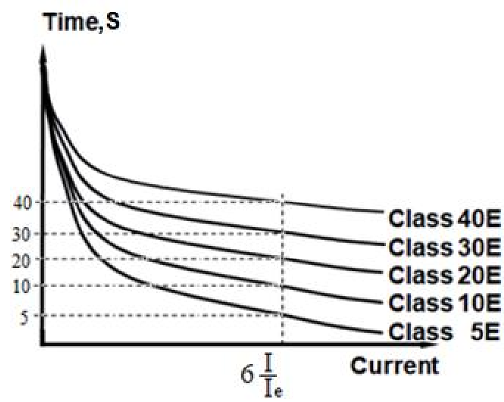

Figure 16 – Tripping curves for overload protection

3.1.2 Long start protection

It is important to prevent the motor from overheating during starting. The rotor could be locked because of an extremely high load or mechanical jam. So, the protection operation in this situation could decrease the motor mechanical damage or thermal stress.

Such protection does not allow a high starting current exceeding the threshold for a time longer than starting time, detecting the long start caused by a locked rotor. So, if the blocking delay is over and the current still exceeds the threshold, the protection is triggered. The delay time must be less than the thermal overload trip at a given threshold current. Protection is enabled only during the motor start-up process, until the current drops below 135% of the nominal current or if the protection class time is over (Table 4). The current and time delay thresholds could be adjusted by a user. This type of protection triggers only a trip, also this function could be disabled. After the start process, the locked rotor protection is performed by a high current protection module.

3.1.3 High Current Protection

Since the long start protection is enabled only during the start-up period, the high current protection is commonly used for locked rotor conditions after the starting period to protect the motor from jams and high overloads. It reduces the thermal stress of the motor and prolongates the lifetime of the motor. And it could operate faster than EOL. The protection has an opportunity to create a trip and a warning (or could be disabled), so it has thresholds currents for each and the function makes a trip only when the current exceeds the threshold for a certain period of time and could operate only after start-up process of the motor (when the starting time exceeds or when the current drops under 135% of nominal one). The trip is delayed allowing the short load peak to disappear.

3.1.4 Low current protection

Low current protection is used to define the underload and loss-of-load conditions. Loss of the load by the motor could mean damages to the mechanisms driven by the motor (loose conveyor, suction loss), so the low current protection is used to prevent it, to protect the power grid and the manufacturing process. Motors in underload conditions consume only current with reactive character - magnetizing current and current to cover frictional losses and should be disconnected from the grid.

Protection could trigger a trip or warning (or be disabled). The trip threshold setting must be set considering the smallest possible load under normal conditions. A trip or alarm would occur if the magnitude of motor current falls below the threshold level for the period of time equal to the time delay setting and it operates only after the motor startup process.

3.1.5 Phase loss protection

Phase loss protection is based on stator currents changes and operates only when the motor is running. This type of protection is active only in case when the average value of the stator currents is greater than 25% of the nominal current and detects phase loss when the currents in the remaining phases are greater than 25% of the nominal current. Such a protection function should not be disabled in real applications, but only for testing purposes. The tripping time is set according to the trip class. The protection function is active immediately after the start command.

Table 5 – Class-depending tripping time for phase loss protection [3].

Trip class	5E	10E	20E	30E	40E
Tripping time	1.5s	3s	6s	9s	12s

3.1.6 Phase Imbalance Protection

This protection function of UMC triggers if the difference ratio between the lowest and greatest of the phase currents (phase imbalance) exceeds a preset threshold. The internal microprocessor imbalance calculation is performed as follows:

$$Imb = 100 \cdot \left(1 - \frac{I_{\min}}{I_{\max}}\right) \quad (14)$$

The protection is active if the average value of currents in the supply phases is greater than 25% of the nominal current. The function could trigger a trip and warning (or be disabled).

Table 6 – Class-depending tripping time for phase imbalance protection [3].

Trip class	5E	10E	20E	30E	40E
Tripping time	2s	3.5s	6.5s	9.5s	12.5s

3.1.7 Phase sequence protection

This protection function is intended to prevent the mechanisms driven by the motor from rotating in the wrong direction – crusher, conveyor. Phase sequence protection requires the motor to have the wires be fed through in the correct order. In that case, the contactor should be located after the UMC100 to keep the same phase sequence even in the case of the contactors switching (reverse starter). If the UMC application contains the voltage module then the wrong phase sequence could be detected even before the motor start, unless without the voltage module it could be detected only after the start command to the motor.

3.2 Ground fault protection

The presence of leakage currents caused by the insulation degradation and damage, aging, moisture, and internal ground connection could lead to further complete failure and high currents.

The detection of the ground fault in the UMC100 could be achieved with the auxiliary device CEM11 or with the UMC's internal calculation. The protection is active only after motor start and could trigger a trip or warning when the earthing current is above the threshold for a defined time. (or disabled)

3.2.1 Ground fault protection based on CEM11

A ground fault could be detected with a very sensitive and high interference immunity zero sequence CT where all phase wires are fed through the same window of the CT and resulting in the zero output current under normal balanced conditions and non-zero in the case of phase-to-ground connection. The CEM11 device monitors the sum of the currents and detects an unbalance current. The signaling output of the device is connected to the digital input of the UMC100. The trigger could be delayed, also this protection function could be disabled during start-up. The CEM11 device could be used in grounded, ungrounded networks and even with high impedance to the ground because of high sensitivity.

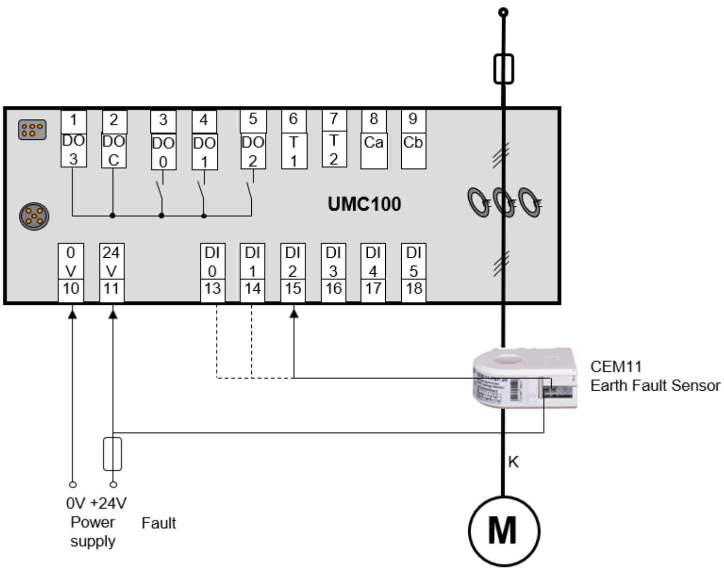

Figure 17 – CEM11 connection to UMC

Table 7 - Technical parameters of CEM11 sensor. [4]

Power supply	24VDC
Consumption	0.5mA
Sizes	20mm, 80..1700mA; 35mm, 100..3400mA; 60mm, 120..6800mA; 120mm, 240..13600mA
Network types	TN, IT, TT

3.2.2 Ground fault protection based on internal calculations

Protection could be implemented without an extra CT but logically inside the UMC using phase currents. This protection function triggers a trip or warning with a certain delay when the unbalance zero-sequence current is above the threshold for a defined period of time after motor start-up. This configuration is less sensitive, and it should be inactive during start-up period due to the high values and asymmetry of the phase currents (especially in no-load conditions). In this configuration, the ground fault current must be >20% of the nominal current to be detected and it only used in networks with low impedance to the ground (only TN networks). The threshold levels must be less than 80% of the nominal current.

3.3 Thermistor motor protection

A thermistor is a semiconductor nonlinear dipole, the resistance of which varies depending on the temperature of the environment in which it operates. The disadvantage is that the temperature change reaction is very quick and sensitive. There are 2 types of thermistors. 1.NTC (Negative Temperature Coefficient) - a thermistor with a negative temperature coefficient of resistance, when its resistance decreases with increasing temperature (increasing electrical conductivity and current). 2. PTC (Positive Temperature Coefficient) - thermistor with a positive temperature coefficient of resistance when its resistance increases with increasing temperature.

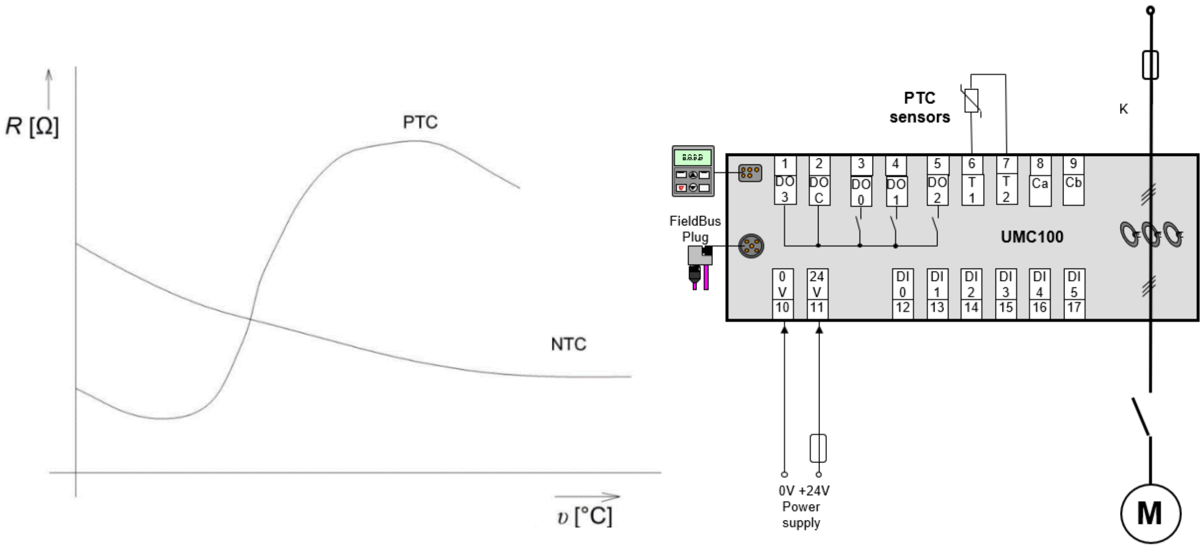

Figure 18 – Thermistor characteristic and sensor connection to the UMC

The Positive Temperature Coefficient polycrystalline ceramic semiconductor elements (thermistors) are inserted in the phases of the stator windings and directly connected to the UMC. The PTC protection is a more accurate method of thermal protection than thermal overload protection. The PTC protection in UMC corresponds to IEC 60947-8 [12] with PTC type A. The rated temperature of the semiconductor should correspond to the type of motor and its insulation. These thermistors have very high positive temperature coefficients with a rapid change of resistance at the rated temperature. The UMC100 detects this rapid change in resistance to define the temperature rise. Also, there is internal supervision against open-circuit and short-circuit failures in the PTC protection circuit. The protection is always active and could trigger a trip or a warning (or be disabled).

3.4 Voltage and power-based protections

The block diagram for voltage and power-based protections is shown in Figure 19.

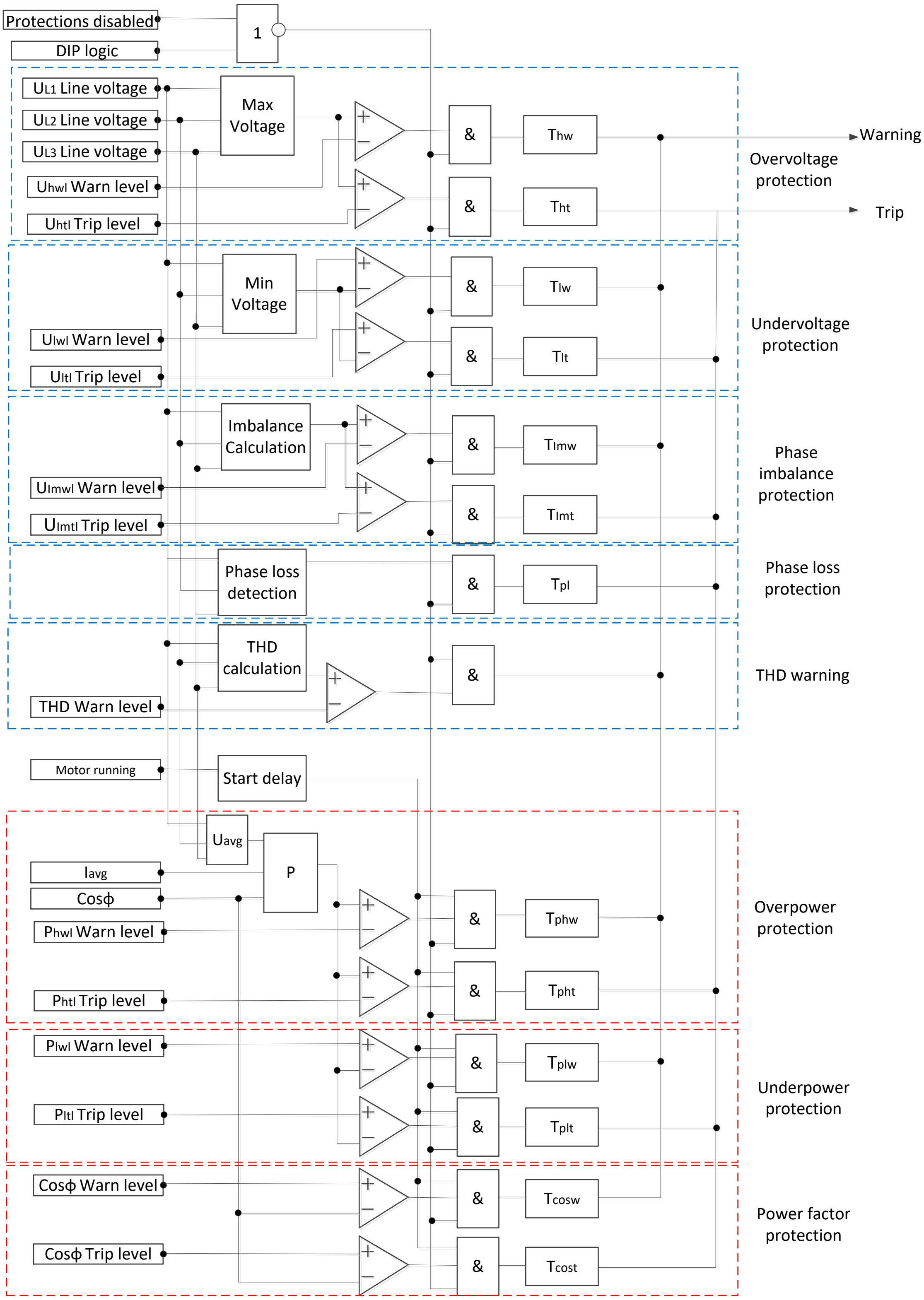

Figure 19 – Block diagram for voltage and power based protections

These functions require the voltage module VI150/155 to measure the motor supply voltage phasor, which is also used to calculate power/energy. All of the voltage/power-based functions could be disabled, also “voltage dip” logic automatically disables all of the voltage-based protections.

3.4.1 Voltage-based protections

The most important advantage of voltage-based protections comparing to current-based protections is the possibility to identify the external faults even when the motor is stopped, and prevent the motor from starting. The voltage-based protections are not active in the test mode. So, the functions are next:

1) Overvoltage protection - Overvoltage results in decreased current and increased iron losses causing the temperature rise. A trip or alarm will occur in case of phase voltage exceeding the threshold for a preset period of time.

2) Undervoltage protection - Undervoltage could consequently result in an increased current and decreased torque, so the undervoltage protection provides advanced warning/trip before the overheating of the motor. A trip or alarm will occur if the phase voltage is less than the threshold for a parametrized time.

3) Voltage dip – sufficient and rapid voltage drop requires load shedding to avoid the blackout caused by undergeneration/overload. This function stops the motor in the case of undervoltage and makes an automatic motor restart once the voltage is back.

Tripped motors could be restarted sequentially to avoid simultaneous connection which could lead to new failure. The voltage restart level is greater than the voltage dip trigger level. The time period when the voltage drops under the voltage dip level and then does not exceed the restart level is called the „undervoltage situation“. If this dip time is less than the preset time parameter „dip autorestart window“ then the motor is not switched off, unless it is tripped and could be restarted after „autorestart delay“. If the motor is switched off and the undervoltage situation time exceeds the permitted “dip duration” then the motor is not restarted.

4) Phase loss protection – detects a missing phase even in the case of the stopped motor, could trigger a trip or warning and it’s possible to set a delay.

5) Voltage imbalance protection – detects a smaller voltage imbalance than a similar current function and triggers a trip/warning when the imbalance exceeds the threshold for a time greater than a delay time. The imbalance level is defined as a ratio of the maximum difference between phase-to-phase voltages to mean phase-to-phase voltage in 3 phases:

$$Uimb = \frac{MaxDifference(U_{12}, U_{13}, U_{23})}{Average(U_{12}, U_{13}, U_{23})} \tag{15}$$

6) Total harmonic distortion – measures the harmonic distortion in the network which could be caused by frequency converters (VFD) or other electronic devices which leads to aging of insulation and motor parts. The THD is determined as a ratio of the power sum of all harmonic frequencies to the power of basic frequency (2). The THD function triggers a warning when exceeds the threshold without delay.

3.4.2 Power-based protections

Power-based protections are useful for devices where the load is not linear to the current difference (pumps, conveyors, fans, compressors) and they provide cavitation protection (not proper suction). Not active in the test mode.

When the asynchronous motor is running at no load, the machine consumes reactive current from the network to create magnetization of the main magnetic circuit, which is independent of the machine load. The engine should therefore work best at full load. Active power and power factor are important parameters for detecting low load or no-load situations, e.g. closed valve. Active consumed power is easily calculated using measured magnitudes of stator current, supply voltage, and phase angle between them. The induction motor load characteristics (Figure 20) show that as the rotor load decreases, the power factor decreases.

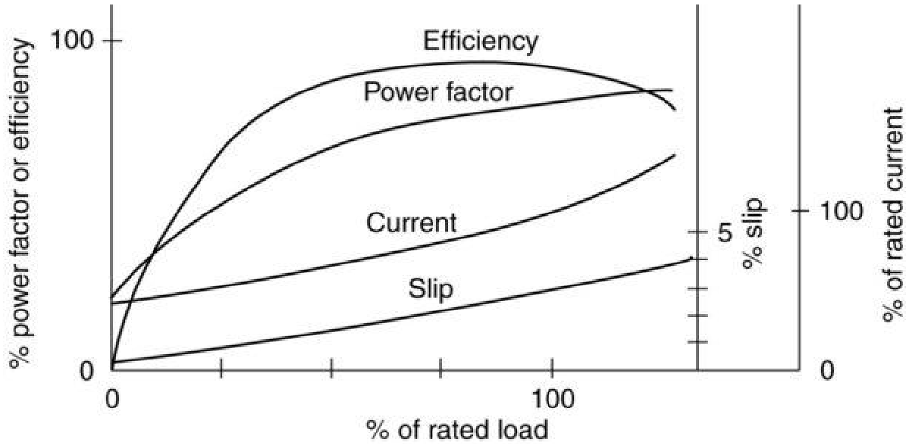

Figure 20 – Induction motor load characteristics [17]

Active power and power factor are required to discover the underload conditions in the case where power changing does not sufficiently cause the stator current change. Power overload and underload could trigger a warning and trip with delays. Power factor protection could trigger a warning or trip in case of a low cosϕ for a certain period to avoid a case with a high reactive component and low active component of a load. These power-based functions are operating only after the starting up the process of the motor with load start delay. Also, it is not recommended to use power factor and active power supervision at the same time.

4 Configuration and types of UMC100 motor control functions

4.1 Ways to start and stop the motor

Start/ stop commands could be received by the UMC from control devices (control stations):

1) Digital inputs – start/stop control with pushbuttons.
2) DCS/PLC – start/stop control using cyclic communication interfaces via fieldbus.
3) LCD panel - start/stop control with buttons on the UMC-PAN panel.
4) Service tool - start/stop control using acyclic communication interfaces via fieldbus.

It is often required to have an allow/block command for start/stop commands, for example – automatic enabled control via digital inputs if the fieldbus communication is lost or to ignore the fieldbus commands during a maintenance period. The UMC100 allows to use 3 control modes to release/block function:

1) Auto (remote). The UMC100 provides a start control function only from DCS/PLC. This mode is activated when the Autobit mode is set as logical “1” on a cyclic fieldbus. The start commands from other sources are forbidden. Only stop can be issued locally.
2) Local 1. The motor accept start commands only from DIs and LCD panel. This mode is activated if the Autobit mode is not set or if UMC detects a bus fault.
3) Local 2. The local mode is forced to set by one of the digital inputs even if auto mode is active.

4.2 Emergency start and the number of starts limitation

An emergency start can be achieved even if the cooling time is not over (block from overload protection). This could be achieved by resetting the UMC100 memory to a cold state.

The emergency start may be performed in 2 ways if the UMC is allowed to do the emergency start (set the parameter “Emergency start” to “On” position): 1) Set one digital input as an emergency start input (DIO-DI2) and send a logical signal “1” to the DI to reset the memory to a cold state. 2) Send a command via fieldbus to reset the UMC thermal memory to a cold state.

To prevent damages to the motor, a limited number of starts function is used. It allows only a limited number of starts “Num Starts Allowed” in the restricted period “Num Starts Window”. It is possible to set a warning or trip command when only 1 start is left in the time window by the parameter “Num Starts Prewarn” and by the parameter “Num Starts Overrun” when no start is left. Also, a pause time after stoppage of motor till the next start "Num Starts Pause" could be defined. The time to the next possible start could be displayed via LCD panel or fieldbus communication.

4.3 Checkback supervision

The UMC is able to check if the motor has been started and can generate a trip if a checkback signal is not received in the preset runtime. It could be done in 2 ways:

1) Monitoring of the motor current. This function makes sure that the stator current becomes greater than 20% of the nominal current within delay time after switching on the main contactor. And it makes sure if the current becomes zero within delay time after switching it off.

2) Auxiliary contact for checking the position of the main contacts of the contactor. The contact must be mounted and connected to the UMC digital input DI0.

4.4 Transparent (measurement) mode

In this mode, the UMC operates as a measuring device. The outputs and inputs are controlled only by the control system and connected to the fieldbus. But the fault output (DO2/DO3) is controlled only by the UMC100. The motor contactor could be switched on/off using a maintaining circuit or a control system. The functions of checkback supervision, UMC controlled start/stop, bus fault warning, and voltage dip/autorestart are not supported in this application of the UMC100.

In the case of a fault, the monitoring signal is sent to the fieldbus and LCD control panel, red LED switches on, but outputs are controlled via fieldbus as before unless the fault output.

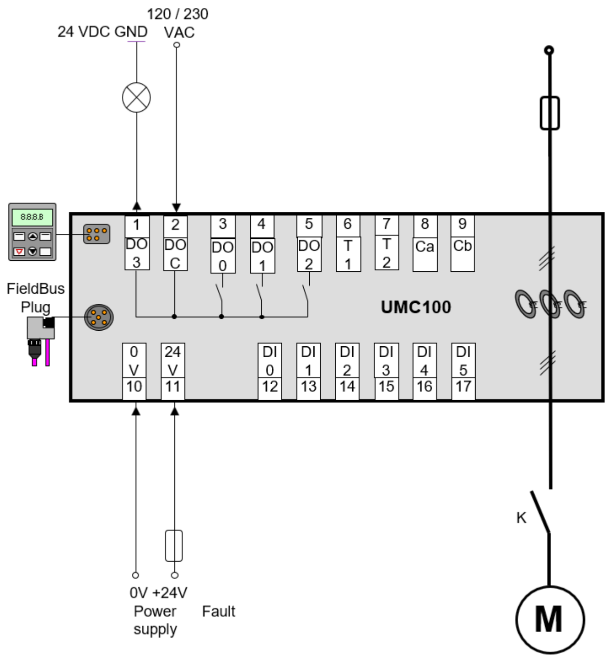

Figure 21 – Circuit diagram of UMC in transparent mode

4.5 Overcurrent relay control function

It substitutes the function of the thermal/electrical overload relay to protect the motor from overcurrent and could be used for standalone applications without fieldbus. The digital output DO0 is normally closed, DO1 is normally open.

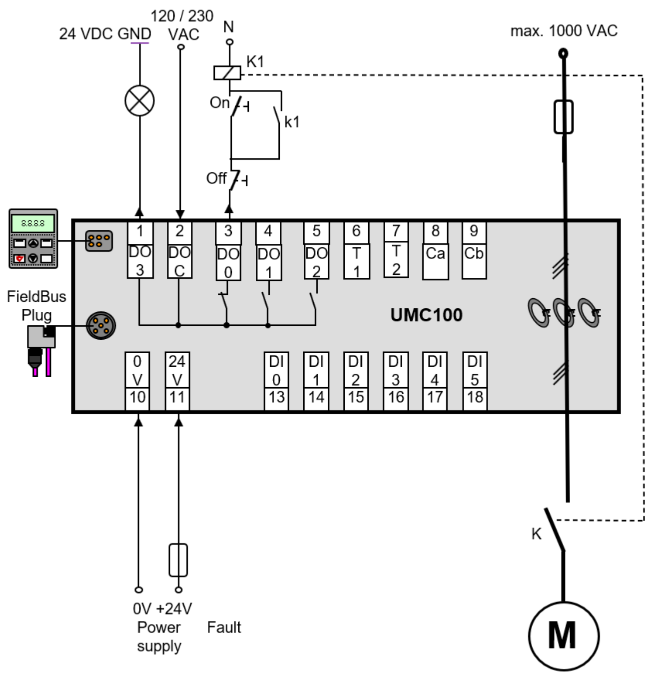

Figure 22 – Circuit diagram of UMC in overcurrent relay mode

In the case of a fault, DO0 switches in an open position, D01 switches in a closed position, fault output (DO3) activation occurs, the UMC sends a signal about the fault to the fieldbus and displays it at LCD panel and red LED. The functions of checkback supervision, UMC controlled start/stop, bus fault warning, and voltage dip/autorestart are not supported in this application of UMC100.

4.6 Direct online starter function

This application is used to run mechanisms in one direction (pumps, fans). Digital output DO0 performs the contactor control. Contactor checkback monitoring can be set via aux contact of contactor at DI0 (or current measurement). Inputs DI4 and DI5 are used to local starting and stopping of the motor using pushbuttons. DO3 output is designated as a fault output with a signal lamp.

When the command to run is received, DO0 closes, switching the main contactor k1 to start the motor. After a while, a checkback signal occurs (from aux contact at DI0 or current monitoring) indicating a successful run performed. If a fault occurs, and a fault signal is received, the command to disconnect the contactor is sent to DO0. The internal signal starts to indicate a fault occurred, the checkback monitoring provides a signal about the motor being disconnected. If a trip was triggered by the overload protection, the cooling time starts to run and it is not possible to perform a run during this period.

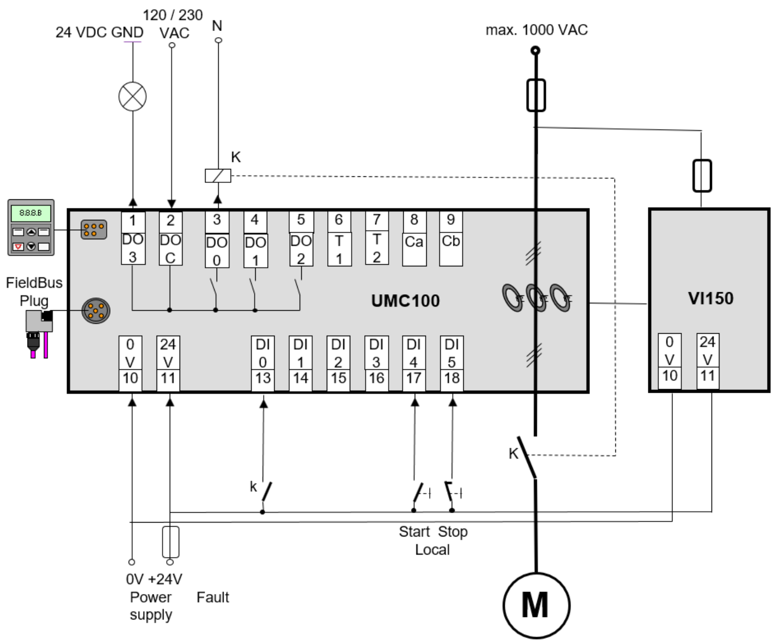

Figure 23 – Circuit diagram of UMC in DOL starter mode

4.7 Forward-Reverse starter function

This function allows the motor to be controlled in two directions (conveyors, pumps). In this mode, the dip/autorestart function operstes in a way to run the motor in the mode which was used before the fault. Presence of the “reverse lock-out time” parameter protects against immediate motor start in the opposite direction.

The relay outputs DO0 and DO1 perform the motor start in forward and reverse direction switching contactors K1 and K2, respectively. DIO could be used as a checkback monitoring input with two auxiliary contacts. DI3 and DI4 inputs are used for a local start commands in forward and reverse directions and DI5 for local stop using pushbuttons. Also, the fault output could be set (DO2/DO3) with a signal lamp and the fault output is controlled only by the UMC itself.

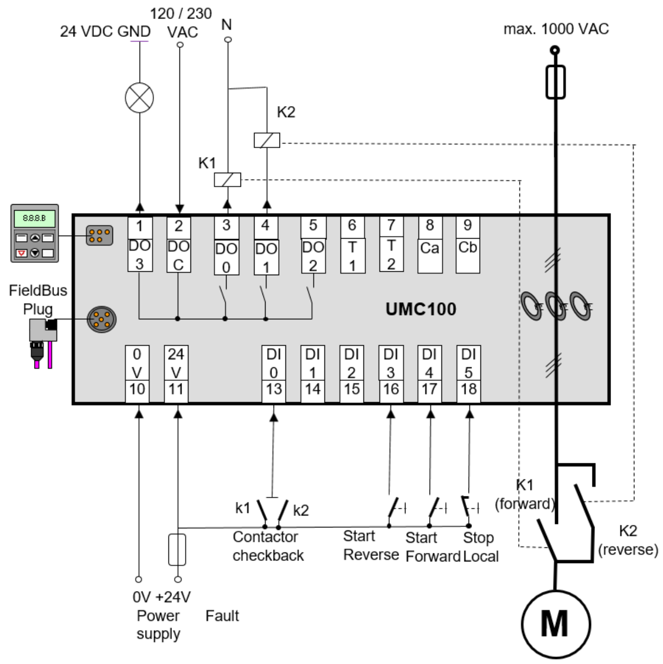

Figure 24 – Circuit diagram of UMC in two directions starter mode

As far as the command „run forward“ is received, the DO0 output switches on the main contactor. And after a delay, the checkback signal provides the internal signal about the successful run. At the moment of the stop command, the UMC switches DO0 input to the open position disconnecting the K1 contactor and the lockout time starts. The checkback signal disappears after some delay time confirming the „OFF“ signal of successful disconnection. During reverse lockout time no reverse start is allowable. After that “run reverse” start could be performed by the closing of the DO1 relay output.

4.8 Y-D starter function

It is used in applications to run the motor in one direction of rotation. The mode switches from star to delta stator windings connection after a defined time (1-360 s) or when the actual current decreases to 90% of the nominal current.

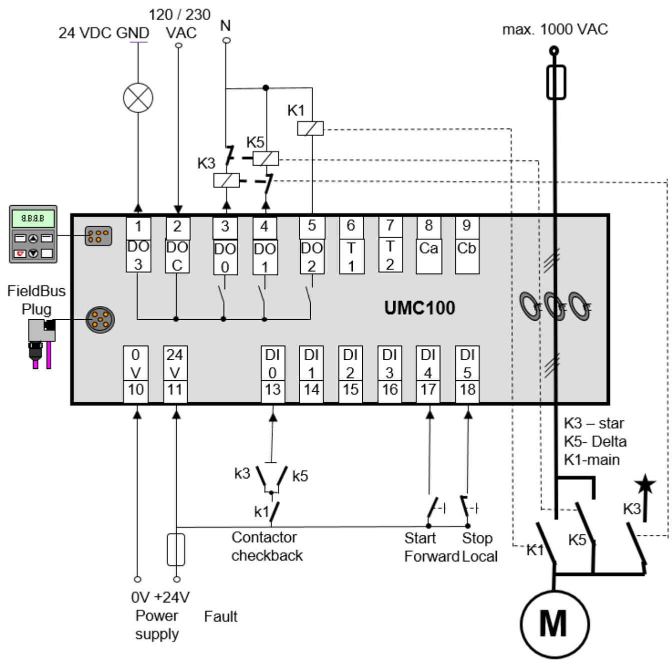

Figure 25 – Circuit diagram of UMC in Y-D starter mode

The outputs DO0, DO1 and DO2 are intended to manage star, delta, and main connection contactors respectively. The input DI0 could be used for checkback monitoring with three auxiliary contacts connected, DI4 and DI5 are intended for the local motor start and stop. DO3 is used as a fault output with a signal lamp and it is controlled by the UMC. This control mode does not support the autorestart/dip function.

When the command to start is received, DO0 output closes and DO2 closes switching on the “star” contactor and main contactor consequently. The checkback monitoring confirms a successful start and provides the signal of running. DO0 opens after a defined starting time, and as far as the checkback signal disappears and some safe pause time is passed, DO1 output closes switching on the “delta” contactor, and checkback confirms successful run of the motor.

4.9 Pole-changing starter function

This function requires a two-speed motor. It is possible to set I_{e1} and I_{e2} as nominal currents in the UMC parameters for 2-speed motors. Speed 1 requires the DO0 output to be closed and speed 2 requires the DO1 output to be closed. The local start could be performed via DI4 and DI3 respectively and stop via DI5. DO3 is used as a fault output with signal lamp, DI0 – as a checkback supervision input with auxiliary contacts k81 and k91 for both speeds (or the current measurement checkback is used).

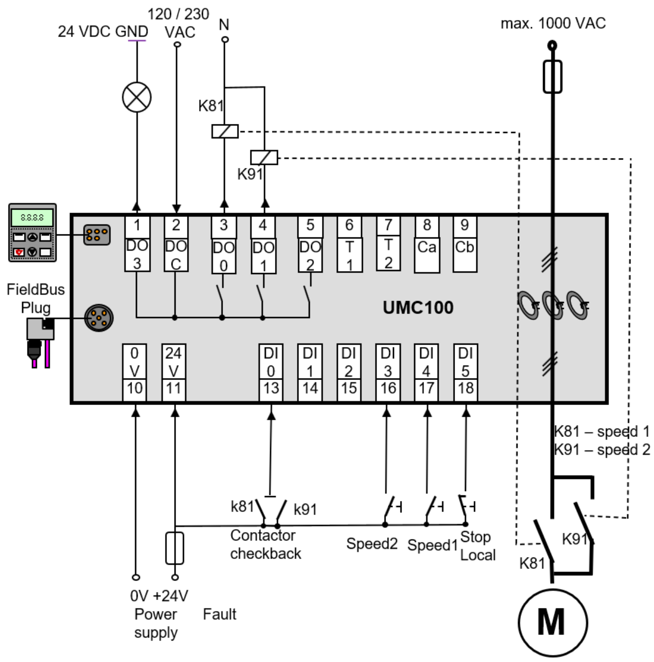

Figure 26 – Circuit diagram of UMC in 2-pole and Dahlander starter modes

Command “RUN FORWARD” leads to DO0 closing, and the checkback supervision insures if the motor is running, and the UMC indicates it. After the command “RUN FAST FORWARD”, DO0 output opens, checkback supervision signals about it, and the UMC waiting a pause time to close the DO1 contact. The checkback monitoring signalizing a successful run and the UMC indicates it.

4.10 Actuator control function

This function is used to open/close valves and flaps. The mode is similar to forward-reverse mode but with limit switches and it has a run-time that is equal to valve closing time. The checkback monitoring via DI and voltage dip/autorestart modes are not supported. DI4 and DI5 inputs work in the inching mode. The actuator functions allow different applications with limit and torque switches and reactions to their position.

Actuator 1 mode: It uses only signals from limit switches: DI0 – the motor is stopped in an open state, and will be started in closing mode, DI1 – the motor is stopped in a closed state and will be started only in opening mode. The signals from torque switches could be used for supervision. The limit switches should be adjusted to consider the inertia of the rotating motor even after being switched off.

Actuator 2 mode: It uses limit and torque switches for operating. DIO limit switch “Open” and DI1 limit switch “Closed” prepare for open state and closed state motor stop, respectively. DI3 torque switch stops the motor and prepares it to start in the opposite direction. If a torque signal is detected and no limit exists, it is assumed that torque occurred during closing, starting is possible after the information about a fault and in the opposite direction.

Actuator 3 mode: In that case, the open position is detected with a limit switch only (as Actuator 1) and the closed position is detected with torque and limit switches (as Actuator 2)

Actuator 4 mode: In that case, the closed position is detected with a limit switch only (as Actuator 1) and the open position is detected with torque and limit switches (as Actuator 2)

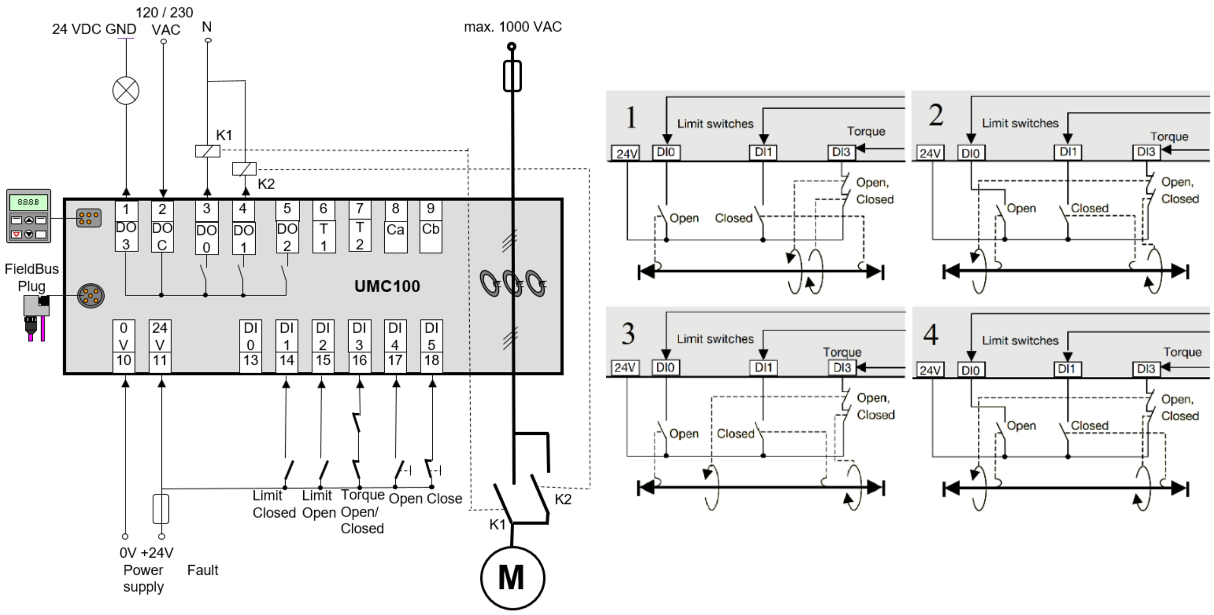

Figure 27 – Circuit diagram of UMC in actuator 1-4 modes

4.11 Softstarter control function

This function is intended to control sofstarter through the UMC as a communication interface and as a functional extension for cheap sofstarters. This function does not allow to use the contactor checkback. Also, during acceleration, functions of frequency check, phase unbalance, phase loss, internal GF calculation, and all voltage based functions are inactive.

Digital outputs DO0, DO1, DO2 are intended to switch on the forward contactor, reverse contactor and provide start/stop signal for softstarter, respectively, DO3 could be used as a fault output to be controlled by the UMC.

In the case of the sofstarter with a bypass signal, DI0 could be used to provide information about reaching the top of a ramp and ramping down. DI3 and DI4 could be used as inputs for local start and DI5 for local stop.

If the softstarter without bypass signal is used, then the ramp-up time setting is used to assume that the motor acceleration is finished and functions could work in normal mode. When the stop signal is received, the UMC opens DO2 and sends a signal tothe softarter to stop the motor, and it could recognize the end of ramp-down by measuring the stator current.

When the UMC receives the command “run forward”, the DO0 closes, disabling the part of protection functions, and DO2 closes with a little delay, starting the ramp-up of the motor by the softstarter and the UMC is performing the current checkback to detect this operation. After reaching the top of the ramp, the bypass signal comes to DI1 and the UMC enables all the protection functions. After stop command, DO2 opens, ramping down starts, and removed bypass signal disables a part of protection functions. After ramping down when the check current disappears and a delay is passed, DO0 opens and switches off the motor.

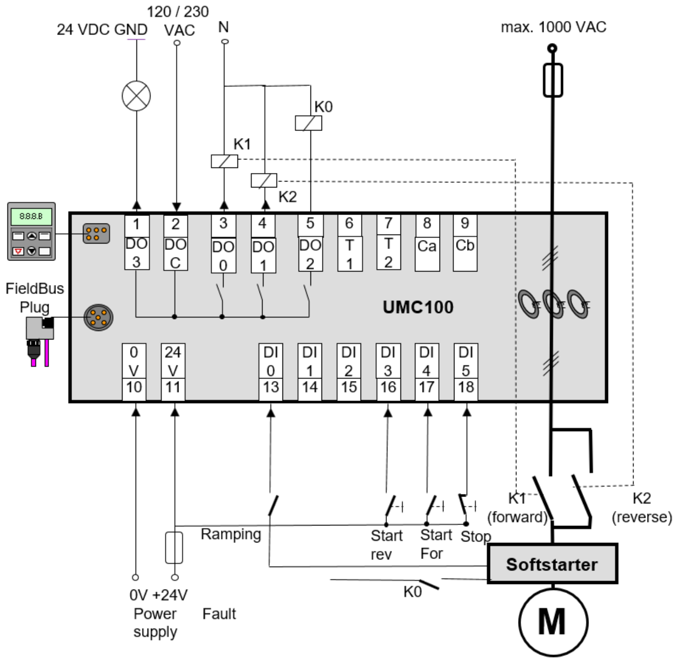

Figure 28 – Circuit diagram of UMC in the softstarter mode

5 The practical assembly and parametrization of the UMC demo testing panel

5.1 Elements and devices used in application

For the testing application, there will be used the UMC100 device with expansion modules, a 3-phase motor to be controlled by the UMC, two contactors for forward and reverse start to be driven by the UMC, and a frequency converter to convert the single-phase power supply into the 3-phase supplying line. An MCB is used for SC protection of the motor. Fuses are used to protect the power supply circuits for VFD and UMC, voltage measuring circuits and the UMC relay output circuits.

Figure 29 – ABB M2AA063B Motor, ABB ACS350 Frequency converter, ABB B6-30-10-80 contactor, A9F04303 Schneider Electric MCB and Ex9BN 1P C16 MCB

5.1.1 UMC100 device with expansion modules

There will be used the UMC100.3 UC specification of the UMC device. Compared to other UMC versions, this specification allows to connect an analogue input module and provides both single-phase and three-phase operation modes, provides a sofstarter control function support, as well as standstill and operating hours supervision. The UMC required supply voltage is 110-240 VAC and it provides the 24 VDC output supply voltage for expansion modules. Also, there is an USB interface for configuration via laptop and availability to display all three-phase currents.

Also, the I/O DX111-FBP.0 module is used. It has a 24 VDC digital input and a connection cable to the UMC. The voltage module VI155-FBP is also implemented with a connection cable. That module specification allows the voltage measurement in ungrounded networks. The operating LCD panel UMC100-PAN is mounted on the UMC device.

5.1.2 Motor

For testing purposes, there will be used the ABB 3-phase motor M2AA063B 3GAA 062 002-ASA in the delta connection. It is a totally enclosed motor with an aluminum stator frame with a squirrel cage rotor and IEC size number 63, it has 2 pole pairs. It is foot mounted motor. The template with its nominal parameters is listed below.

Table 8 – Motor parameters template [8]

U, V	f, Hz	n, min^{-1}	P, kW	I, A	cosϕ	I_s/I_n	T_n, Nm	T_s/T_n	T_{max}/T_n	J, kgm^2
400 Y	50	1370	0.18	0.8	0.64	3	1.25	2.2	2.6	0.00028
230 D	50	1370	0.18	1.4						
460 Y	60	1660	0.22	0.8						

5.1.3 Frequency converter

The frequency converter in this application won't be used for start performing, but only for a single-phase to three-phase network conversion, because the start will be performed by the UMC controller. For this purpose, the ABB ACS350-01E-02A4-2 converter is selected. The main selection principle is to make sure that the nominal power, output current and output voltage ratings are sufficient to feed the selected motor.

Table 9 – ACS350-01E-02A4-2 parameters [10]

Nominal power	0.37 kW
Input supply configuration	1-phase input
Input frequency f1	50 Hz
Input voltage rating U1	200..240 VAC
Input current rating I1	6.1A
Output frequency f2	0..500 Hz
Output current rating I2	2.4 A
Output voltage range U2	0..U1

5.1.4 Contactors

There are two contactors of the ABB B6-30-10-80 type selected. These are 3-pole contactors with one NO auxiliary contact and screw terminals. The selection principle is based on the nominal main circuit parameters (power, voltage, and current) to be equal or greater than corresponding motor parameters and the ability to withstand the starting (locked rotor) current. In addition, the control circuit supplying with 230 VAC is important for connection simplicity. The NO auxiliary contact helps for contactor state monitoring for the UMC device.

Table 10 – ABB B6-30-10-80 contactor parameters.

Number of poles	3
Rated voltage of the main circuit	690 VAC / 220 VDC
Rated voltage of the aux. circuit	690 VAC / 250 VDC
Rated frequency of the control circuit	400 Hz/50 Hz/60 Hz
Rated frequency of the main circuit	50 Hz/60 Hz/DC
Rated power AC-3 for 230V	2.2 kW
Rated control circuit voltage	220..240 VAC
Rated Short-time Withstand Current	64 A for 10s from the cold state
Conventional Free-air Thermal Current	Main Circuit 20 A
Full Load Amps Motor Use	(220...240 V AC) Three Phase 6.8 A

5.1.5 Miniature circuit breakers

The A9F04303 Schneider Electric (QF2) is selected as a protection device against SC in the motor circuit. The nominal ratings must be equal to or greater than the nominal parameters of the motor. The C trip characteristic with tripping current equal to 5..10 times of nominal current is selected as recommended for motors with low and medium inrush currents. The nominal current of MCB is selected a bit larger than the motor current in terms to execute the overload trip by UMC and not by a circuit breaker.

Table 11 – A9F04303 Schneider Electric MCB parameters.

Number of poles	3
Current rating	3 A
Trip characteristic	C
SC breaking capacity	6 kA
Rated voltage	400 VAC

The Ex9BN 1P C16 MCB (QF1) is selected as a switching device for the whole panel in terms to provide necessary safety measures and to have an opportunity to switch the panel on and off when it is required.

5.1.6 Fuses and cables

According to the Technical data of ACS350 User Manual [14] (pages 293-294), the cables and power supply fuse selection guide for the 01x-0204-2 type of VFD is next:

Table 12 – Power cable and fuses requirements for ACS350 [14]

Fuse	gG class with rating I1..10 A
	T class with rating I1..10A
VFD supply cables (U1, V1, W1)	Cu 2.5 mm^2
Motor cables (U2, V2, W2)	Cu 0.75 mm^2
PE cable	Cu 2.5 mm^2

According to the Technical data from the UMC100.3 Catalog [4], the switching capacity per relay contact of the UMC at 240 VAC is 1.5 A. Moreover, the connection cables for voltage measurement by the VI155 module may require additional cable protection. So, the selected cables and fuses are shown in table 12.

Table 13 – Fuse and cable selection

ASC350 power supply cables	Cu 2.5 mm^2
Motor supply and voltage measurement cables	Cu 1.5 mm^2
UMC connection cables	Al 1mm^2
ACS350 supply protection fuse	T class glass tube 250 VAC, 6.3 A
UMC100 supply protection fuse	T class glass tube 250 VAC, 1 A
Voltage measurement cable protection fuse	T class glass tube 250 VAC, 5 A
Digital relay output protection fuse	T class glass tube 250 VAC, 1.5 A

5.1.7 Terminal blocks

For the connection, the WAGO280-101 terminals are used. As fuse terminals, the RSP 4 Elektro Bečov terminals are used. Their parameters are listed below.

Table 14 - WAGO280-101 terminals parameters.

Rated voltage	800 V
Rated current	18 A
Rated cross-section	2.5 mm^2
Wire connection method	Clamp

Table 15 - RSP 4 Elektro Bečov terminals parameters.

Rated voltage	250 V
Rated current	6.3 A
Short-time withstand current	1500 A
Rated impulse withstand voltage	4 kV
Rated cross-section	4 mm^2
Wire connection method	Screws

Figure 30 – RSP 4 Elektro Bečov fuse terminals and WAGO280-101 terminals

5.2 Electrical power connection

The electrical power connection diagram is shown in Figure 31.

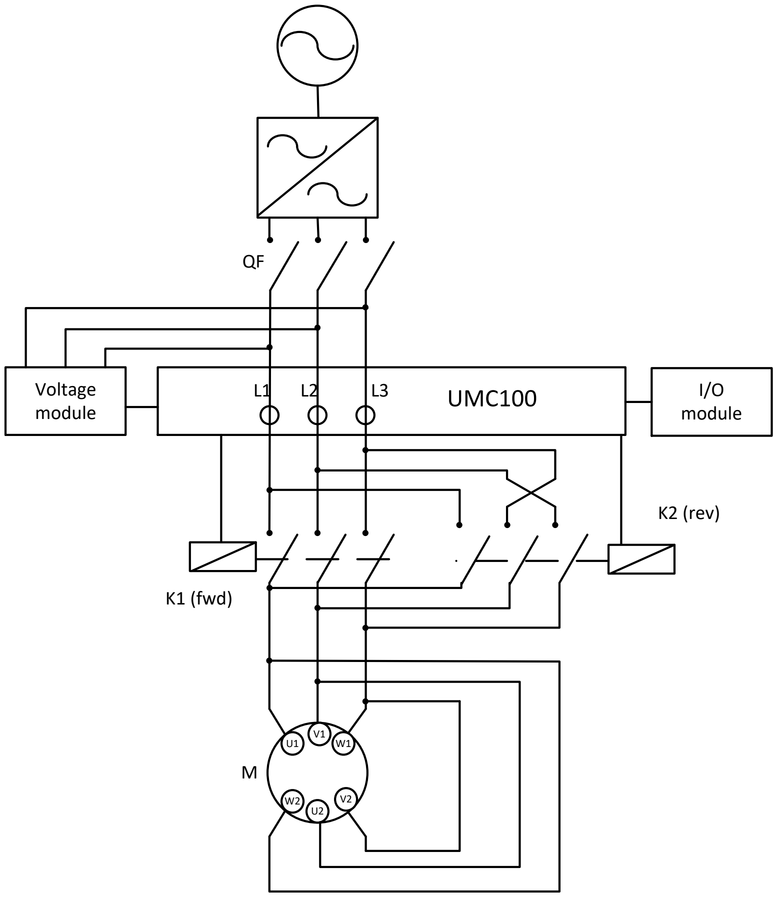

Figure 31 – Electrical power connection diagram

The electrical power source used in this application is a 230 VAC single-phase source (socket).

The frequency converter is supplied with a 230 VAC single-phase source and converts it into the 3-phase 230 VAC voltage, so it operates as the 3-phase source for the motor.

The MCB (QF) purpose is to protect the motor from the short circuit since the contactor by its operation principle is not intended to disconnect SC currents and does not contain an arc suppression solution.

The UMC100 operates in a three-phase mode with voltage measurement.

This application is in the two-directional starting mode (forward and reverse) with a direct online connection of the motor to the supply line. This starting mode was selected due to the low power of the motor and low starting current ratio. Such application does not require any additional starting conditions in terms to decrease the starting current and torque, because their values are not so sufficient. For a reverse start, there is required to change the phase sequence to make the electromagnetic field rotate in the opposite direction as well as a mechanical rotation of the rotor, consequently.

The stator winding of the motor is performed in the delta connection of phases in terms to be supplied by the 230 VAC line voltage.

5.3 UMC100 wiring diagram

The wiring diagram is shown in Figure 32.

The UMC is supplied with a 230 VAC source (socket) as well as a frequency converter. MCB QF1 is intended for the complete disconnection of the demo panel from the power supply in terms of safety. The frequency converter is protected from overcurrents by the FU1 fuse, and the UMC device is protected by the FU3 fuse.

The DOC terminal of the UMC is also connected to the 230 VAC phase conductor in terms to provide the required voltage to the contactors supply circuit. The contactor supply circuit contains a fuse FU2 to protect the relay output contacts of the UMC. The UMC trip unit controls the digital output signal switching. The digital outputs DO0 and DO1 are connected to the terminals of the contactors' coils and provide a control circuit voltage to them as the corresponding output is switched on. The LEDs HL7, HL8, and HL9 are used to demonstrate the presence of the digital output signals for the demo panel. The UMC provides a 24 VDC output voltage to be used for DI signals and expansion devices supplying. The k1 and k2 elements are the auxiliary NO contacts of the corresponding contactors K1 and K2, both of them are intended to provide a "1" logic signal to DI0 for the contactor checkback function. The QS1-QS6 elements are the electrical switches used to force the "1" and "0" signals at DIs manually. The LEDs HL1-HL6 are intended to demonstrate the presence of a 24V signal at the inputs for the demo panel. The rheostat R1 is connected to T1 and T2 terminals in terms to simulate the PTC protection function by variating its resistance.

The DX111 and VI155 modules are connected via Ca/Cb connection cable to the UMC and supplied from the 24 VDC UMC output. The DX111 module also has manually operated digital inputs via switches QS7, QS8, a signal presence could be demonstrated by LEDs HL9 and HL10 respectively. The common ground for inputs 1DI0-4 must be connected to 1DIZ to force an internal logic to operate.

The VI155 module voltage measuring circuit is connected to phases L1, L2, L3 respectively, and each phase connection circuit contains a fuse to provide additional cable protection.

The power motor circuit contains an L2 phase disconnecting pushbutton SB1 to simulate a power source line loss to test the protection function.

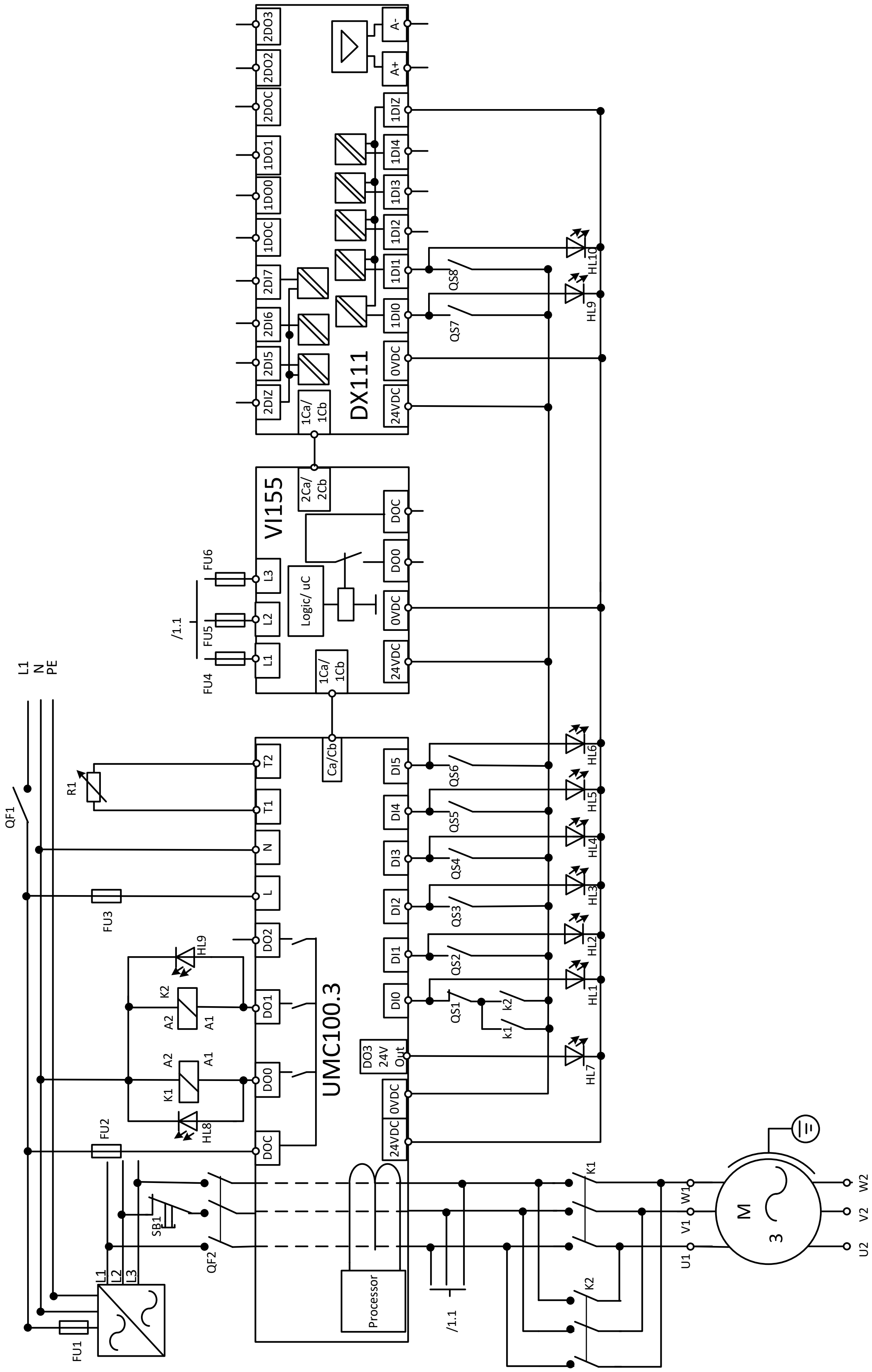

Figure 32 – Wiring diagram

5.4 General arrangement of devices and elements.

The layout drafting of the demo panel with all elements is shown in Figure 33, and the actual arrangement is shown in Figure 34.

All devices are assembled on a wooden plate with an area 500x450 mm with usage of 2 DIN-rails 35 mm wide. The motor is foot-mounted to the wooden board. The LED lamps, switches, and rheostat are arranged on the plexiglass plate which is placed above the wooden board and fasten to the board with 4 long bolts.

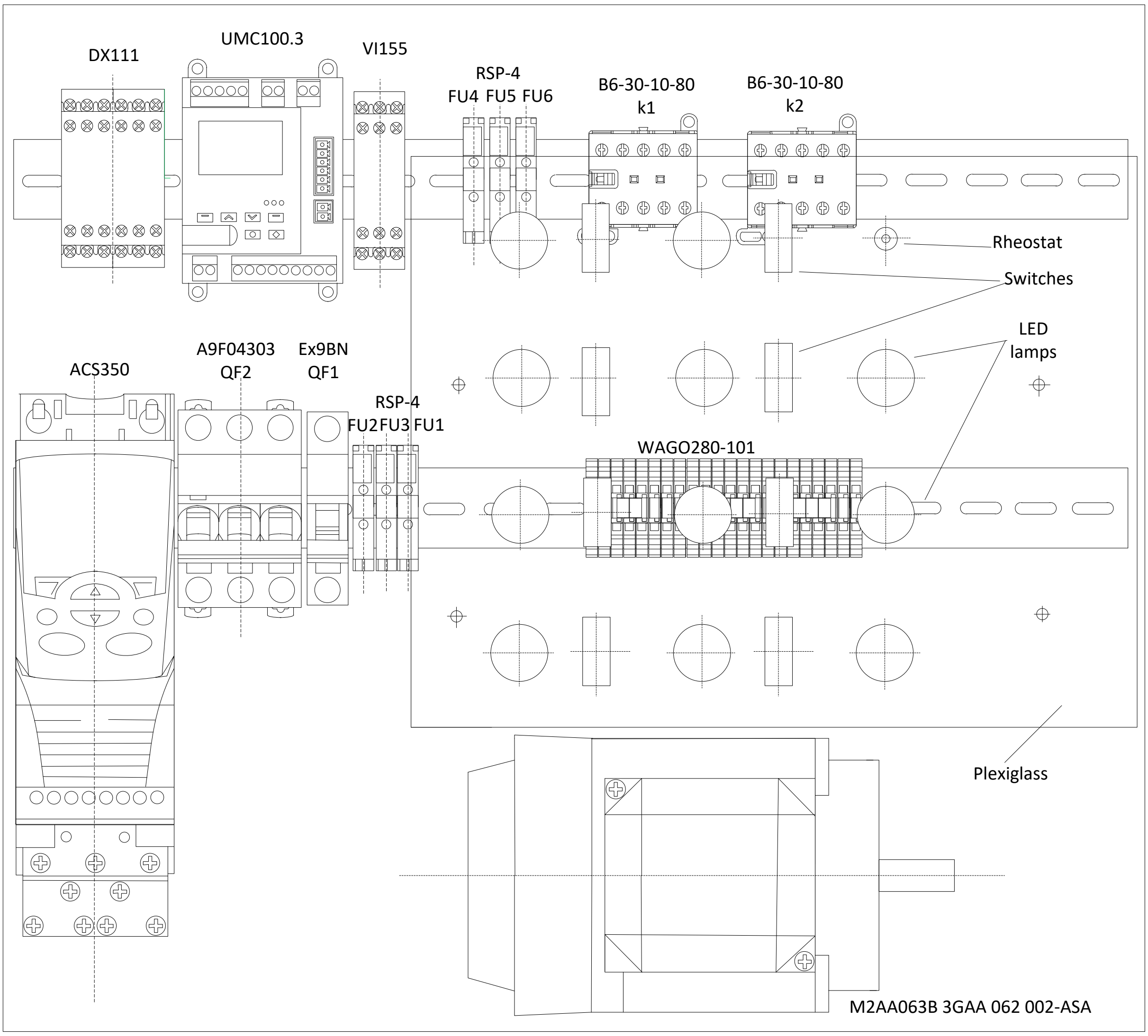

Figure 33 – Demo panel layout

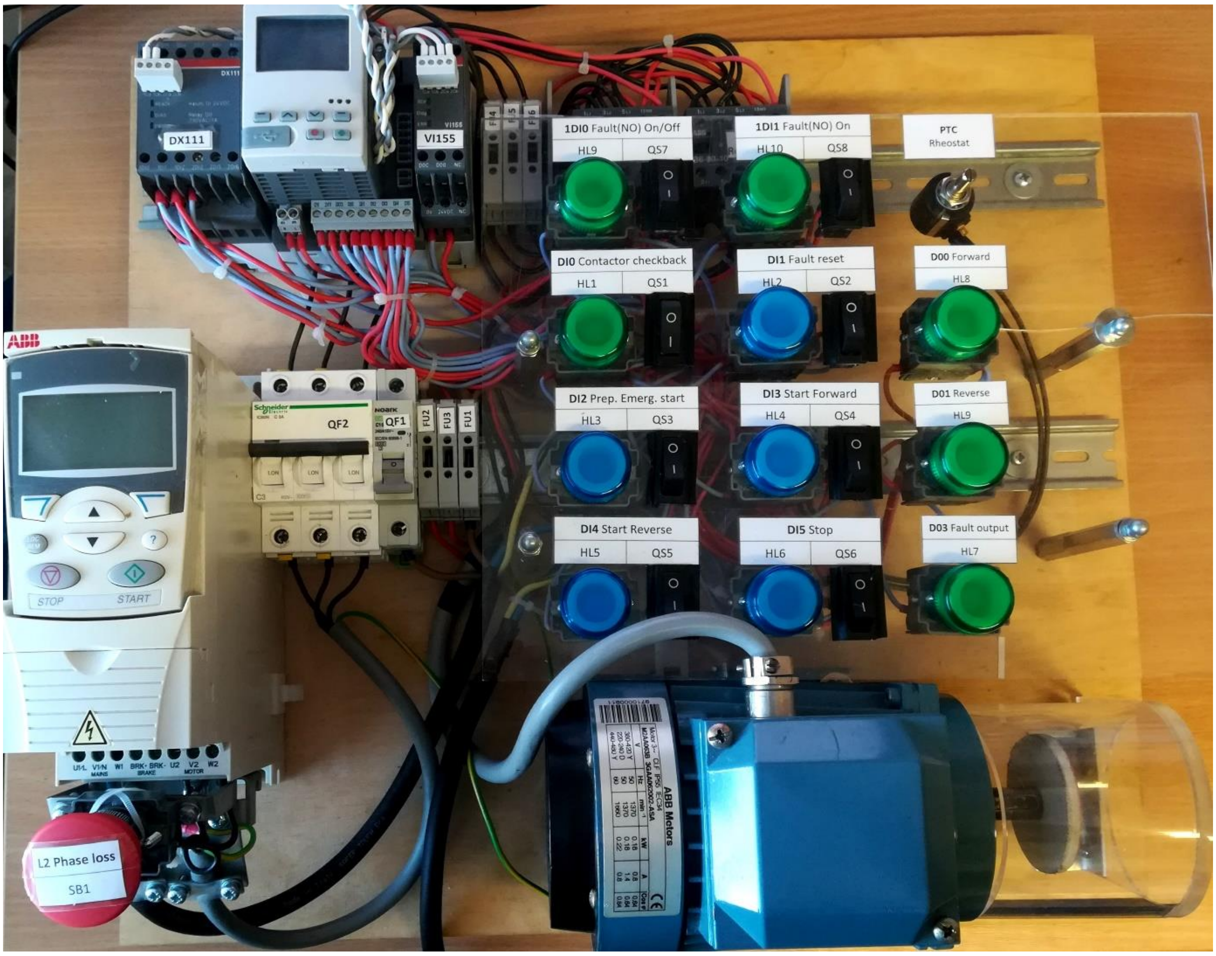

Figure 34 – Demo panel arrangement

5.5 Frequency converter parametrization

The VFD parametrization is performed with the usage of the control pad. The operation conditions could be set as local or remote – in local starting conditions it is possible to variate the output frequency (and voltage, consequently) during the motor running.

Table 16 – ASC350 frequency converter parametrization

Application macro	ABB STANDARD
Motor control mode	SCALAR:FREQ
Nominal motor voltage	230 V
Nominal current	1.4 A
Nominal frequency	50 Hz
Nominal speed	1370 rpm
Nominal power	0.2 kW
Nominal torque	1.4 Nm
Motor pole pairs	2
Acceleration time	0
U/f ratio	LINEAR

The set start-up data is next: The application macro is set a default value “*ABB STANDARD*”, which is suitable for most cases. The motor control mode is set to “*SCALAR:FREQ*”, which is commonly used for test purposes with even no motor connected. This mode is selected since no control is required from the frequency converter. The acceleration time is set to zero to perform a direct online connection. The U/f ratio is set to be linear for proportional variation of voltage and frequency.

5.6 UMC100 parametrization

The UMC100.3 parametrization could be done using the LCD control panel manually or configuration software – ABB Asset Vision Basic and ABB Field Information Manager, both of which can provide custom application editor functions.

5.6.1 Motor management parametrization

The *"Control function"* parameter is set to *"Reverse starter"* in terms to provide a two-directional possible rotation of the motor. This function selection automatically parametrizes DO0 for a forward start and DO1 for a reverse start, also DI3 and DI4 as the local start command inputs for reverse and forward start respectively, and DI5 as a local stop command input.

The "*Rev lock-out time*" parameter is set to "2 s" and it parametrizes the locking time after motor stoppage before run in opposite direction is allowed.

The "*Fault output*" is set as "*Flash DO3*" – a 24 VDC output which represents the fault output behaviour in the case of the fault signal from the UMC. In our case, the fault signal causes the LED connected to DO3 fault output to blink.

The "*Number of phases*" parameter is selected as "*3 Phases*" due to the three-phase load to make the UMC detect parameters properly.

The supervision parameter "*Checkback*" is set as "*Contact DI0*" which means that the checkback monitoring will be achieved by an auxiliary NO contact signal of the contactor at DI0 (and not by a phase current). And the "*Checkback time*" parameter is set to be "1 s" – the maximum delay between the moment when the relay digital output is closed and the moment when checkback signal appears at DI0.

Invert control inputs setting for "*Inv DI start input*" and "*Inv DI stop input*" are set to "*NO*" in terms to have all inputs in NO state and not in NC state.

The "*Emergency Start*" setting is set to "*On*" to allow the emergency to start via digital input.

The "*Fault autoreset*" parameter is in "*Off*" position to force the protection faults to be acknowledged and reset manually by the operator and not automatically.

Multifunction inputs settings DIO-DI2:

1) The parameter "*Mutif. 0,1,2 delay*" is set to "0 s" to trigger the input functions without delay.

2) "*Multif 0,1,2 auto reset*" is set to "No" to reset the fault message from DI manually after checking it by the operator.

3) "*Multifunction 1*" parameter is set as "*Fault reset*" to make this function available to reset fault conditions message locally at DI1.

4) "*Multifunction 2*" parameter is set as "*Prep. Emergency start NO*". It means that an external signal at DI2 resets the UMC thermal memory to a cold state and it allows a start even after an overload trip.

Limit the number of starts settings:

According to "Low voltage motors – Motor guide" [7] (page 51, Table 4.3), the highest permitted number of starts per hour at no-load conditions for motors of 63 IEC motor size with 4 poles is equal to 8700 (145 per minute). The actual number of starts per hour under load could be calculated as (16). Let's consider the maximum variable load inertia applied to the motor in testing purposes is 10 times greater than motor inertia to find the minimum number of starts possible in that case:

$$S = S_0 \cdot \frac{J_{motor}}{J_{motor} + J_{load}} = 8700 \cdot \frac{1}{1+10} = 790,9 \ \frac{1}{\mathrm{h}} = 13,2 \ \frac{1}{\min} \tag{16}$$

Where,

S – permitted number of starts at some load, h^{-1}

S_0 – permitted number of starts at no load, h^{-1}

J_{motor} – moment of inertia of the motor, $kg \cdot m^2$

J_{load} – moment of inertia of the load, $kg \cdot m^2$

So, the parameter "Num Starts Allowed" is selected to be "13" and "Num Starts Window" is "1 min". "Num Starts Pause" parameter is set to "1 min" to avoid the motor start right after its stoppage. "Num Starts Overrun" parametrizes the reaction in the case if no start is left anymore in the defined time, and its function is set to "trip". "Num Starts Prewarn" function defines the reaction when the only one start left and this function is set to "Warning".

All management parameter settings are in the table below.

Table 17 - Motor management parameters

Number	Parameter name	Option
1	Control function	Reverse starter
2	Rev lock-out time	2 s
3	Fault output	Flash DO3
4	Number of phases	3 Phases
5	Checkback	Contact DI0
6	Checkback time	1 s
7	Inv DI start input	No
8	Inv DI stop input	No
9	Emergency Start	On
10	Fault autoreset	Off
Multifunction input settings		
11	Mutif. 0,1,2 delay	0 s
12	Multif 0,1,2 auto reset	No
13	Multifunction 1	Fault reset
14	Multifunction 2	Prep. Emergency start NO
15	Emergency Start	On
Limit the number of starts settings		
16	Num Starts Allowed	13
17	Num Starts Window	1 min
18	Num Starts Pause	0
19	Num Starts Overrun	Trip
20	Num Starts Prewarn	Warning

5.6.2 Current based protection parameters.

The rated current setting "Setting I_{e1}" is "1.4" A according to the rated current of the motor. The "Current factor" is set as "100 %" since no eternal CT is presented and only one feed-through wiring method is used. (if an external CT is used, the parameter is set as value of transformation ratio multiplied by 100%, for a few feed-through wiring the parameter value is equal to the number of loops)

Overload protection parameters

To select the “Trip class” setting for an overload trip it is important to know the maximum starting time of the motor and its starting current ratio to avoid an excessive trip. The maximum starting time calculation according to [7] (page 52) could be achieved as next:

From the motor parameters in Table 8 it is known that $T_s = 2.2 \cdot T_n = 2.75 \text{ Nm}$, $T_{\max} = 2.6 \cdot T_n = 3.25 \text{ Nm}$, $J_M = 0.00028 \text{ kgm}^2$. Let’s take values for the maximum possible variable load on the shaft (in testing purposes) as next: $T_L = 2 \cdot T_n = 2.5 \text{ Nm}$, $J_L = 10 \cdot J_M = 0.0028 \text{ Nm}$, $K_L = 1$. Then,

$$T_M = 0.45 \cdot (T_s + T_{\max}) = 0.45 \cdot (2.75 + 3.25) = 2.7 \text{ Nm} \tag{17}$$

$$T_{acc} = T_M - K_L \cdot T_L = 2.7 - 1 \cdot 2.5 = 0.2 \text{ Nm} \tag{18}$$

$$K_1 = 2 \cdot \pi \frac{f}{p} = \frac{2 \cdot \pi \cdot 50}{2} \tag{19}$$

$$t_{st} = \frac{J_M + J_L}{T_{acc}} \cdot K_1 = \frac{0.00028 + 0.0028}{0.2} \cdot 157 = 2.4 \text{ s} \tag{20}$$

Where

t_{st} – starting time, s

J_M – moment inertia of the motor, kgm^2

J_L – moment inertia of the load, kgm^2

K_1 – speed constant (p-number of pole pairs)

T_{acc} – acceleration torque, Nm

T_M – motor torque, Nm

T_L – moment of the inertia of the load, kgm^2

K_L – load type coefficient

T_s – starting torque, Nm

$T_{\max}$ – starting torque, Nm

Considering the starting current ratio $I_s = 3 \cdot I_n$, in Figure 35 we could see that the point of the maximum starting current and time is located under the tripping curve of class 5E overload characteristic and it suits our purposes. The 5E characteristic is used mostly for applications that require a fast trip, so it will be suitable for testing and demonstration of operation.

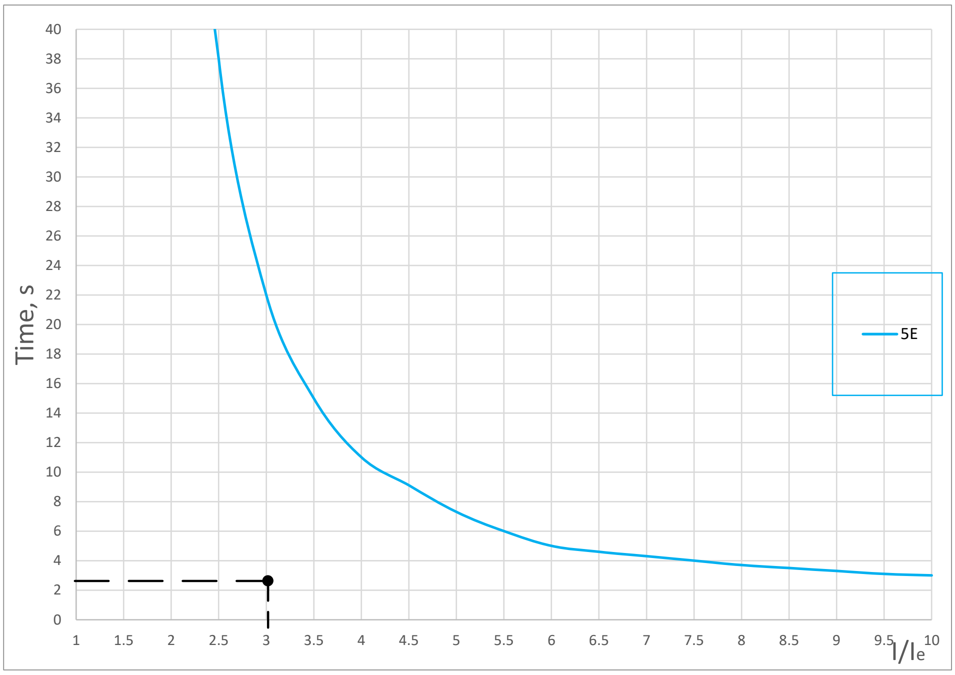

Figure 35 – Overload curve selecting.

"Cooling mode" is defined as time-depended and not the thermal level dependent. That means that the motor could be started after an overload trip in the defined time. And the cooling time is set equal to 60 s.

Long start protection

For the current and time delay threshold settings of this protection, it is important to know the actual starting current and starting time in the current application. Since in the demonstration purposes the motor in the demo panel is working in highly underloaded conditions, the actual mean starting time and starting current values measured and displayed by UMC are next: $t_{st} = 0.1$ s, $I_{st} = 170$ %.

So, to make the protection operate sensitively, the current threshold must be lower than the actual starting current to detect the start conditions (k -safety coefficient), and the time delay must be greater than the normal starting time to make sure that the normal start can be performed. In this case, thresholds are next: $T_{locked} = 1$ s

$$I_{locked} = I_{st} \cdot k = 170\% \cdot 0.9 = 153\% \qquad (21)$$

Also, we must be sure that the time delay for the given current threshold is less than the time delay for EOL protection for the same current. And the delay time must be less than safe stall time for a motor – 40 s according to [7] (page 49). In our case, it is safe enough.

Phase loss protection parameter is "On". In our case for the 5E overload trip class, the time delay for the phase loss protection is 1.5 s due to the internal UMC parameters for each protection class.

Current imbalance thresholds could be various and depend on the application and motor design. Let's set the lowest thresholds from recommended to obtain fast and sensitive protection trigger. But still, these settings will allow short high-level negative sequence transients to avoid maloperation. The delay time is set to 2 s due to the UMC parameters for 5E protection class. Trip settings: $I_{imb.t} = 15$ %, $t_{imb.t} = 2$ s; Warning settings: $I_{imb.w} = 10$ %, $t_{imb.w} = 2$ s.

Phase sequence protection is enabled in L1L2L3 order to supervise the phase sequence and it triggers a trip. To operate this function in the proper way for a reverse starter, the contactors are mounted after the UMC so the phase sequence through the UMC does not change.

Low current protection threshold is highly dependent on the actual load and it is disabled in the particular application in our demonstration case with no constant load.

High current protection current setting is the same as for long start protection since the purpose of this protection is to detect the motor jams. The time delay is selected to be sufficient to not operate in short-term overloads and it should be less, than safe stall time for the motor. Trip settings: $I_{hct} = 153\ \%,\ t_{hct} = 10\ \text{s}$; Warning settings: $I_{hcw} = 135\ \%,\ t_{hct} = 10\ \text{s}$.

Ground fault protection will be disabled in testing application

PTC protection is enabled, and its reaction is set to “Trip” in case of fault detection

All the settings are listed in the table below

Table 18 - Current based protection functions settings

N	Function	When active	Option	Threshold	Delay
1	Overload protection	Always	Trip	5E inverse characteristic	
2	Long start	During start	Trip	153%	1 s
3	Phase loss	Always (I>25%I$_e$)	Trip		1.5 s
4	Current imbalance	Always (I>25%I$_e$)	Trip	15%	2 s
			Warning	10%	2 s
5	Phase sequence	Always	Trip	-	-
	Low current	Disabled			
7	High current	After start	Trip	153	10 s
			Warning	135	10 s
8	Ground fault	Disabled			
9	PTC	Always	Trip	-	-

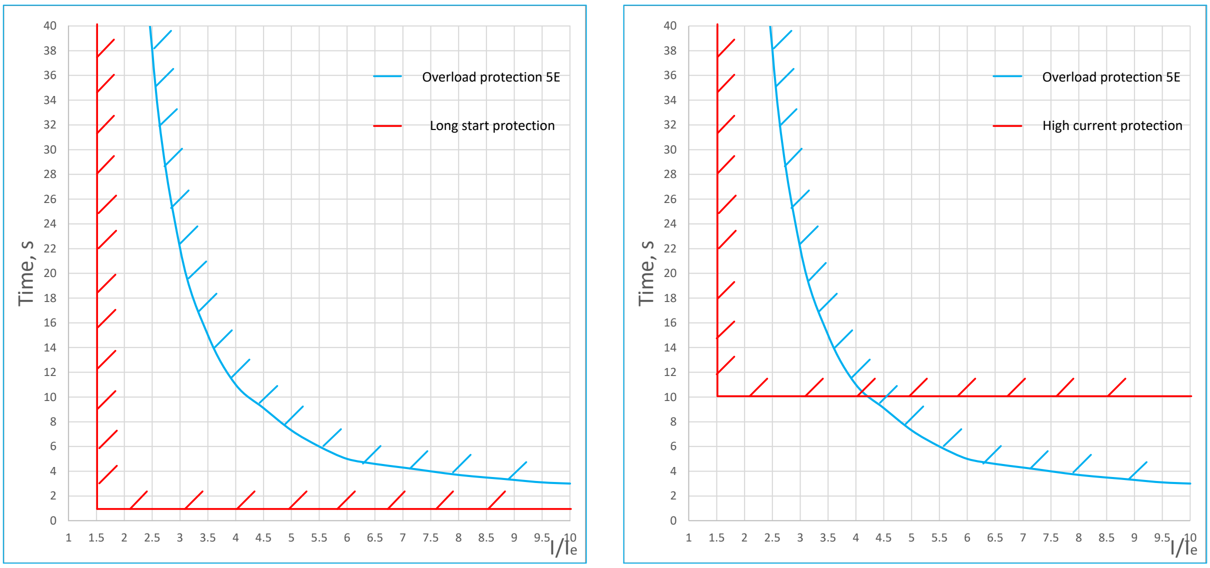

Figure 36 – Current protection schemes during the motor start (left) and after start (right).

5.6.3 Voltage based protection parameters

For voltage protection functions6 the voltage module V15x should be enabled in the UMC parameters and "Nominal line voltage" is set to 230 V.

Low voltage protection

Since the motor start could lead to sufficient voltage drops, this value should not be high. Also, technical standards require motors to continuously operate at 90% of the nominal voltage level. The recommended threshold is 80-90%. Trip settings: $U_{lt} = 85$ %, $t_{lt} = 1$ s; Warning settings $U_{lw} = 90$ %, $t_{lw} = 1$ s.

High voltage protection

Motor standards require electrical machines to be able for continuous operation at 110% of the rated voltage. So, the thresholds: Trip settings: $U_{ht} = 115$ %, $t_{ht} = 1$ s; Warning settings: $U_{hw} = 110$ %, $t_{hw} = 1$ s.

Voltage imbalance protection

Since the voltage unbalance leads to the high negative-sequence currents and even small voltage unbalance causes high current unbalance when 5% voltage imbalance leads to 30% current imbalance, it is not recommended to allow the unbalance more than 5%. Trip settings: $U_{imb} = 5$ %, $t_{ht} = 1$ s; Warning settings: $U_{hw} = 3$ %, $t_{hw} = 1$ s.

THD warning

According to IEC 61000-2-2 [9] for low-voltage equipment with the rated current under 16 A, the maximum admissible harmonic distortion is equal to 8%. So, the settings: $THD_w = 8$ %, $t_{THDw} = 5$ s.

Power and power factor based protection functions are applied to certain load so they are not used in this application.

All settings are listed in the table below

Table 19 - Voltage based protection functions settings

N	Function	When active	Option	Threshold	Delay
1	Low voltage	Always	Trip	85%	1 s
			Warning	90%	1 s
2	High voltage	Always	Trip	115%	1 s
			Warning	110%	1 s
3	Voltage imbalance	Always	Trip	5%	1 s
			Warning	3%	1 s
4	THD warning	Always	Warning	8%	5 S
5	Power and PF functions	Disabled			

5.6.4 IO module parameters

These are parameters for the DX111 expansion module.

"Missing module reaction" is set to trigger an "Error" reaction, "DX1xx Enable parameter" has to be set as "On". The parameter "DX1xx DI delay" is set as "3 ms".

Aux input block parameters

The fault reset behaviour "*Aux inp 1-6 ack mode*" is parametrized as "*Manual reset*" to be acknowledged by the operator.

The digital input 1DI0 function "*Aux Inp 1 reaction*" is parametrized as "*Fault (NO) Motor in On/Off*". That means that an external signal of the fault from another device (or simulated manually) could be received by UMC from 1DI0 input of DX111 and trigger a trip of the UMC unit, and it is allowed to trigger the UMC always – does not matter if the motor is running or stopped.

The digital input 1DI1 function "*Aux Inp 2 reaction*" is parametrized as "*Fault (NO) Motor in On*". That means that UMC could receive a trip signal from 1DI1, and it happens only when the motor is running.

"*Aux Inp 1-6 delay*" parameters are set to "0" to cancel the input delays.

Table 20 - Motor management parameters

Number	Parameter name	Option
1	Aux inp 1-6 ack mode	Manual reset
2	Aux Inp 1 reaction	Fault (NO) Motor in On/Off
3	Aux Inp 2 reaction	Fault (NO) Motor in On

6 Tests and measurements of UMC100 application functions

6.1 Tests of UMC100 control functions

6.1.1 Start and stop functions.

The timing diagram of the demo panel signals during the start and stop processes is shown in Figure 37. Its description is listed below.

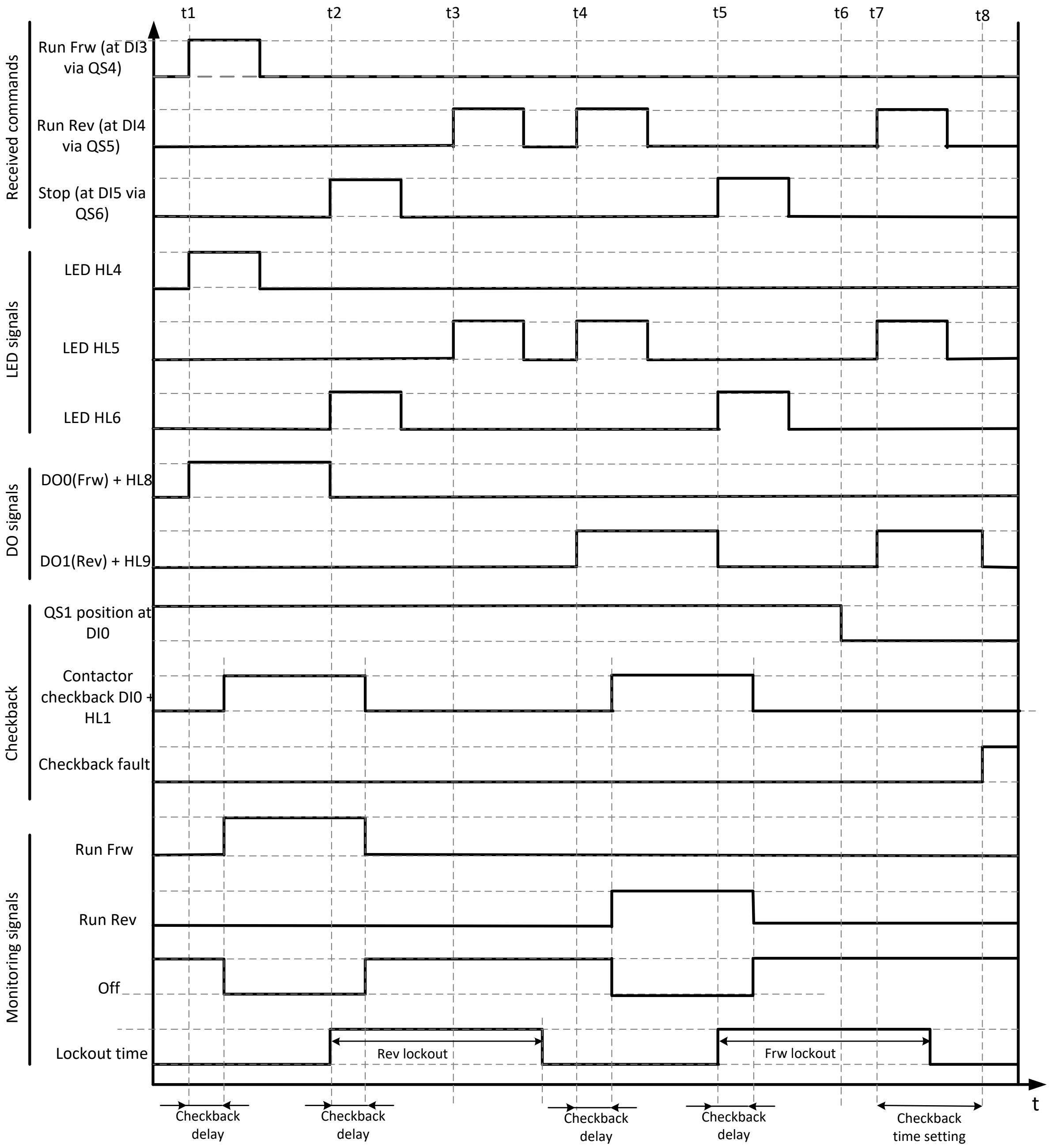

Figure 37 – Timing diagram for start and stop control functions

At the point t=0 QF1 and QF2 MCBs are in position "On", the frequency converter is already operating and supplying voltage to the demo panel. The ACS350 is in the remote regime and the mode "Start" is active.

1) The „Run Frw" command is performed at t1 moment with short-term usage of the switch QS4 (also could be performed via the UMC-PAN). The LED lamp HL4 indicates an appearance of a signal at the DI3 input. The UMC device receives a command and closes DO0 in terms to provide a control

voltage to the contactor coil, the HL8 lamp shows an output signal presence. After that, the UMC waits for a checkback signal about the successful operation from an auxiliary contact of the contactor k1. The checkback signal appears with a small delay at DI0 and activates the HL1 lamp. The UMC processes this checkback signal and establishes the internal monitoring signal about a successful run being performed and indicates it by a yellow LED at the UMC-PAN.

2) The “Stop” command is received at t2 moment by pressing the QS6 switch (or by UMC-PAN command). A logical “1” signal is sent to DI5 and displayed by HL6 lamp. The UMC receives the signal and opens DO0, the HL8 lamp turns off. The reverse lockout time starts. The checkback signal from the auxiliary contact of the contactor k1 disappears at DI0 after the delay time, HL1 is off. A monitoring signal of a run is off and the green LED is active on the UMC-PAN.

3) If we try to run the motor in the reverse direction at some moment t3 (when the lockout time is on), there will be no start performed. The signal is provided to DI4 using QS6 switch and HL6 indicates it, but the UMC does not switch the outputs.

4) The command „Run reverse“ is applied successfully after lockout time at t4 moment. The UMC switches on the DO1 output providing the control voltage to the k2 contactor coil, and the HL9 lamp is on. The auxiliary contact switches and sends the signal to DI0 forcing the HL1 lamp to light on. The UMC receives this checkback signal and establishes a monitoring signal of running reverse.

5) The “Stop” command at t5 makes the UMC open the DO1 output and then the HL9 lamp is out. The UMC waits for the checkback signal to disappear and establishes “Off” as a monitoring signal.

6) Let’s say at some moment t4 the contactor checkback circuit is interrupted by switching off the QS1 switch at DI0 and no checkback signal could be received by the UMC since then.

7) An attempt to start the motor reverse again at t7 makes the motor switch on the DO1 output again and wait for the checkback signal for the parametrized time. When the checkback time setting is over and still no signal at the DI0 input, the UMC switches off DO1 and establishes a checkback fault with the unique message “Checkback relay” on the LCD panel.

6.1.2 Demo panel behaviour during fault conditions.

The timing diagram for demo panel signals during fault conditions is shown in Figure 38. The description is listed below.

1) At the beginning, the motor is stopped. At the moment t1 the switching of QS8 is performed and an external fault signal to the 1DI1 input is sent, the HL10 lamp is activated. But there is no reaction of UMC since it is parametrized to trigger the external fault signals from 1DI1 input only if the motor is running (and do not react when the motor is stopped).

2) At the moment t2, the QS7 switch is switched on and there is an external fault signal at the 1DI0 input signalized by HL9. The fault is triggered by the internal trip logic and a monitoring signal about the fault is established, there is a red LED on UMC-PAN and the „Aux DI1“ message at the LCD panel. The fault output DO3 is flashing to signalize the fault and the HL7 lamp is blinking.

3) The fault reset by QS2 at DI1 is performed at t3 moment and indicated by HL2 LED (also fault reset could be performed via UMC-PAN). All fault signals are acknowledged and erased.

4) The motor is started forward by the switch QS4 at t4 time moment, there is a signal on DI3 input and DO0 output.

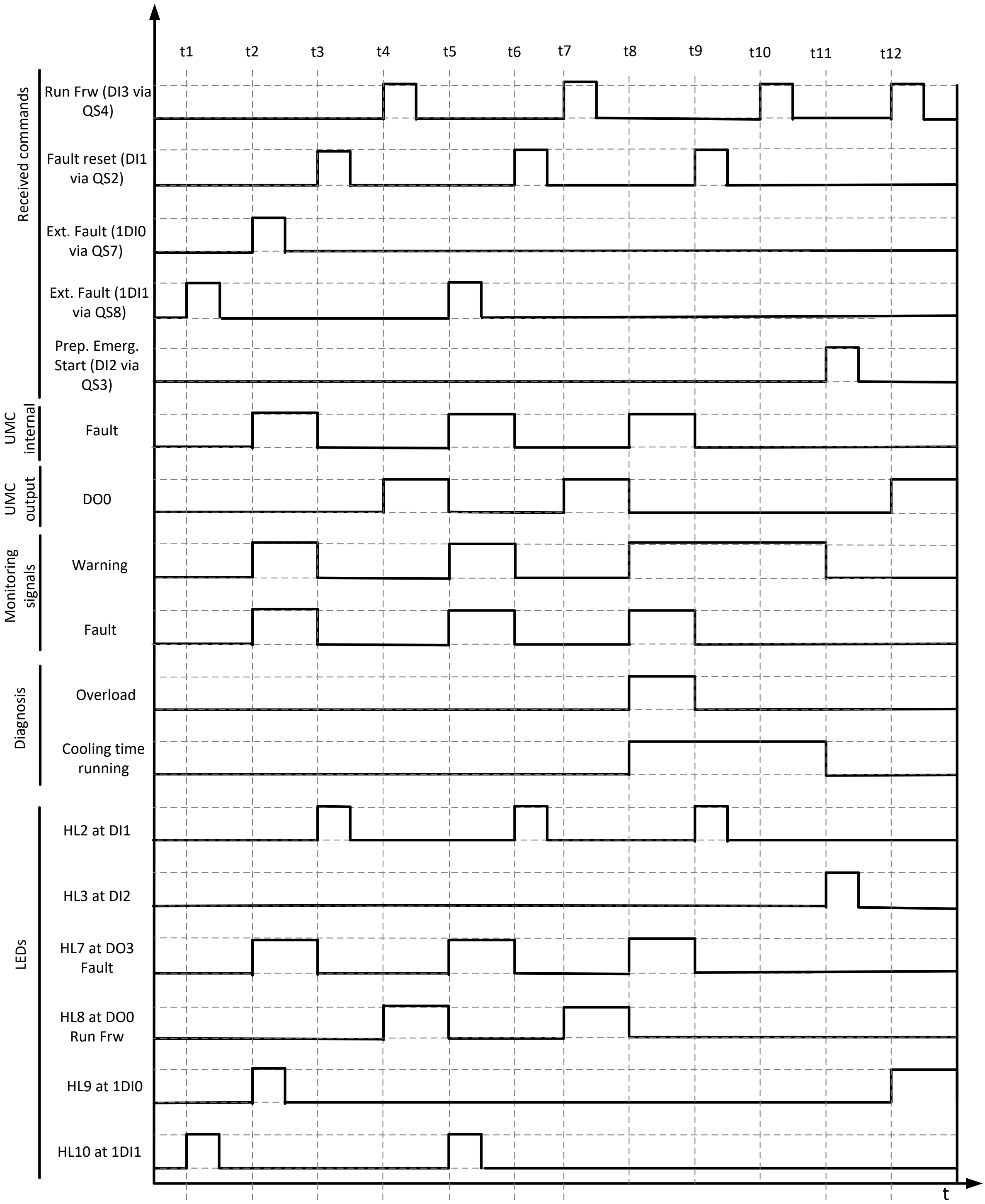

Figure 38 – Timing diagram for the UMC fault behaviour.

5) An external fault signal is sent to the 1DI1 via QS8 at the t5 time moment. The HL10 lamp signalizes a signal presence at the input. And now it triggers the fault logic (since the motor is running), DO0 is switched off, the motor is disconnected from the power supply and the fault could be acknowledged by red LED at the UMC-PAN and „Aux DI2“ message on the LCD display, as well as flashing lamp HL7 at DO3.

6) At the moment t6 the fault reset is done, and all the fault signals are gone.

7) At the t7 moment, a start is performed again.

8) Some protection operation (let's say overload protection) happened at t8 moment. The fault logic is in work and the trip is achieved. There is a special fault message on the LCD screen ("Thermal overload trip" in case of overload protection operation). The cooling time of the motor is started.

9) There is a fault reset at the moment t9.

10) If there is an attempt to start the motor in some moment t10 when the cooling time is not over, a start will not be performed.

11) At the time t11 the "Prepare Emergency Start" command is received by the UMC from DI2 by switching QS3. The HL3 lamp registers the presence of an input signal at DI2. The UMC memory resets to the cold state and a warning is gone.

12) At t12 after resetting UMC to the cold state (or when the cooling time is over), a normal start can be done.

6.2 Tests of UMC100 protection functions

6.2.1 Long start protection

The long start protection function is simulated by means of the preliminarily mechanically blocked shaft of the motor before starting. Then the start attempt is performed. The UMC device registers a high current exceeding the protection threshold for a period longer than the protection time setting and triggers a trip with the message "Locked rotor" on LCD. Three experiments have been done. The currents and starting times before the trip have been measured and displayed at the UMC-PAN display. The results are in the table below.

Table 21 – Testing of the long start protection parameters

	I_{L1}, A	I_{L2}, A	I_{L3}, A	I_s, %	T_s, s	Threshold, %	Time setting, s
Experiment 1	3.64	3.87	3.90	278	1.1	153	1
Experiment 2	3.63	3.85	3.88	277	1.1		
Experiment 3	3.80	3.96	3.90	284	1.1		
Mean	3.69	3.89	3.89	279.7	1.1		

6.2.2 Phase Imbalance protection

The phase imbalance protection operation is simulated using a rheostat that is inserted in the power line conductor L1. The wiring diagram containing the R2 rheostat in L1 line is shown in Annex A. The rheostat parameters are in the table below. The photo of the panel with a rheostat is shown in Figure 39.

Table 22 – Rheostat R2 parameters.

Nominal current, A	4 A
Nominal voltage, V	500 V
Maximum resistance, Ω	39 Ω

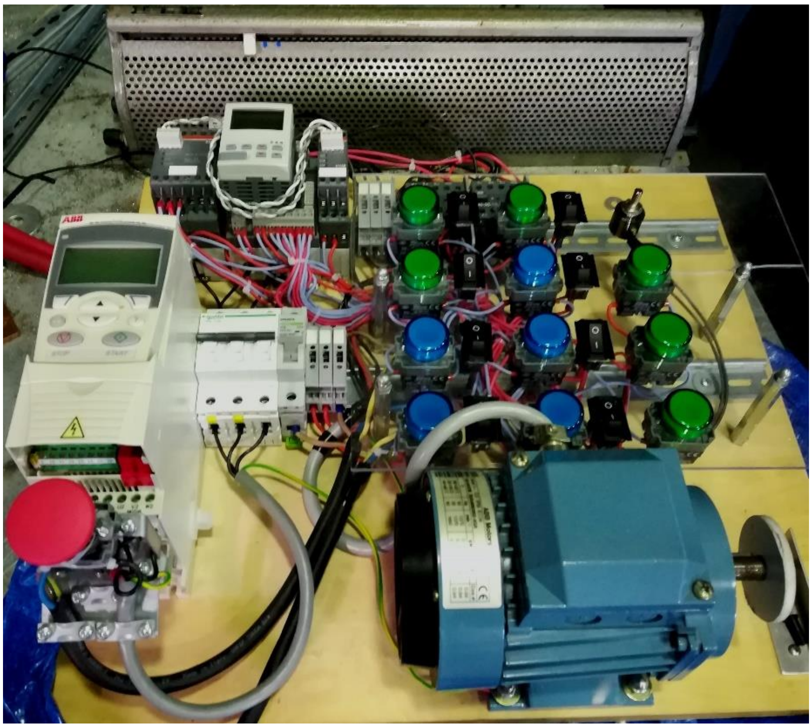

Figure 39 - Demo panel with regulating rheostat

An increase in the resistance of the rheostat inserted in the line conductor causes a drop in the line current. When the motor is running, the value of the rheostat's resistance is being gradually increased from zero to a certain value. Then the current in the L1 conductor drops sufficiently and the UMC device triggers a trip with the message "Phase imbalance" on LCD. Three experiments have been done. The line currents at the trip point have been measured, the imbalance has been calculated by the formula (14), and a trip resistance of the rheostat has been defined with a multimeter.

Table 23 – Testing of phase imbalance protection function

	I_{L1}, A	I_{L2}, A	I_{L3}, A	R2, Ω	Imbalance, %	Trip threshold, %
Experiment 1	1.07	1.28	1.21	8.2	16.406	15%
Experiment 2	1.07	1.28	1.20	8.3	16.406	
Experiment 3	1.07	1.27	1.21	8.5	15.743	
Mean value	1.07	1.277	1.207	8.33	16.185	

6.2.3 Phase loss protection

As it was mentioned before, the SB1 pushbutton is used for the phase loss simulation and it is inserted in the L2 supply line conductor (Figure 34). The pushbutton is in the NC position and breaks the L2 line when pressed.

If the demo panel is turned on but the motor is stopped, then the phase loss detection is performed by a voltage measurement. During normal conditions, the line-to-line voltage is approximately 240 VAC. Under fault conditions, the line-to-line voltage between the two unaffected phases is still around 240, but the voltage between the damaged phase and the unaffected phase is two times less – around 120 VAC. The UMC reacts and defines a fault condition with the message "Phase loss (I/U)" on the LCD. The protection function triggering time is measured in several experiments and found as 0,7-1,1 s between pressing the pushbutton and UMC fault signalization. The measured values before and during fault conditions are shown in Figure 40 as well as the phasor diagram for voltages.

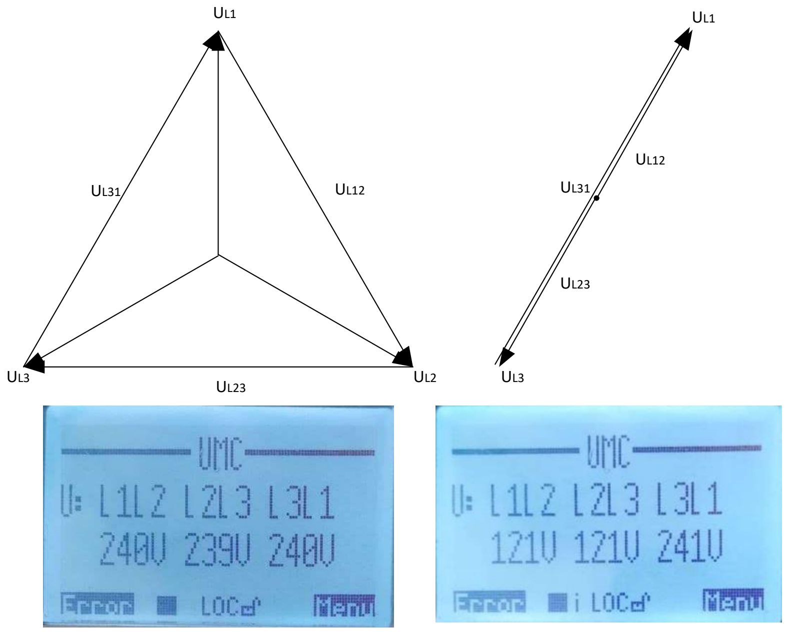

Figure 40 – Phasor diagrams and measured values for voltage before (left) and during (right) phase loss experiment.

If the motor is running, the phase disconnection results in noise and vibrations caused by uneven torque produced by the remaining phases, but the motor is still running even if its speed is reduced. The current in the affected line equals zero, in the remaining phases it is increased for electromagnetic reasons – because the power transmitted to a shaft is almost constant and the remaining phases are doing additional work to keep it still. The UMC detects the fault conditions and triggers a trip with the fault message “Phase loss (I/U)”. The approximate trip time between establishing a fault and the contactor disconnection is about 1.8-2 s. The measured values of current before and during fault conditions are listed below.

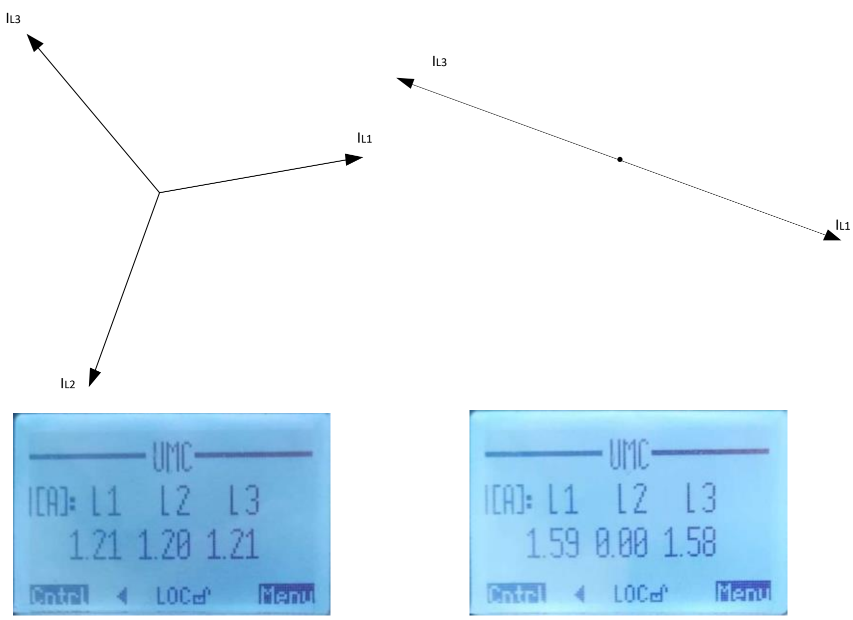

Figure 41 – Phasor diagrams and measured values for current before (left) and during (right) phase loss.

6.2.4 Undervoltage protection

The undervoltage situation is simulated by the operation of VFD – ABB ACS350. A voltage variation is achieved by the variation of an output frequency of the VFD. To variate the output frequency of the VFD during its operation it is necessary to switch the "REM" regime of operation to "LOC" at the LCD panel of ASC350. Then, the output frequency can be variated even during a motor run. The lower the output frequency, the lower the output voltage. The U/f characteristic is selected to be linear, so the change in frequency and voltage is proportional (Figure 42). At the start, the panel is supplied by 50Hz 230VAC voltage. Then, the frequency and voltage are slowly decreased by local control of the VFD to achieve an undervoltage trip. The fault is recognized and a trip is performed by the UMC when the output frequency of the VFD is around 42-43 Hz and the trip voltage measured by the VI155 and displayed by the UMC-PAN is around 195 V. But an output voltage of the VFD could be unstable when a frequency is not equal to nominal, so the trip could be achieved in a wide range of output frequency. The fault message on UMC-PAN is "Voltage out of spec". The protection function is available always - when the motor is stopped and when it is running.

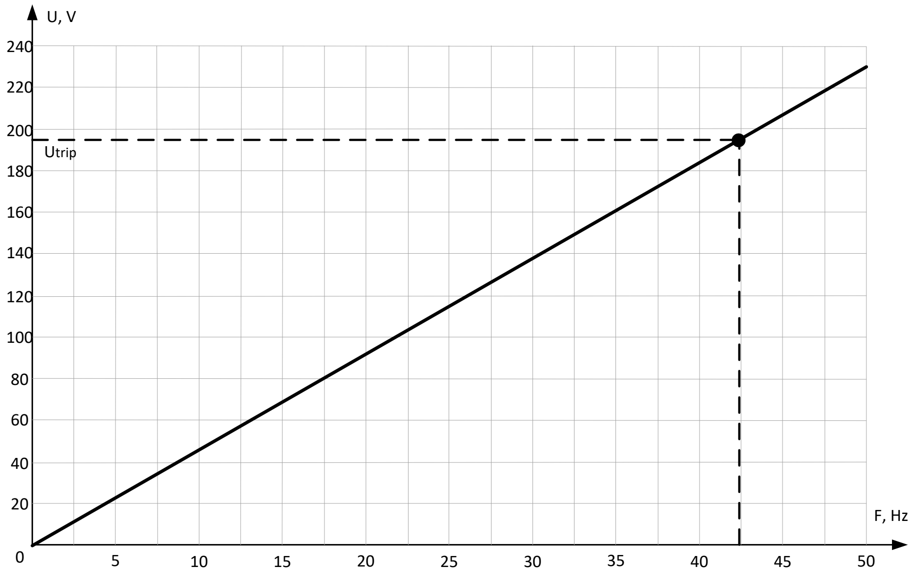

Figure 42– U/f characteristic for VFD and tripping point.

6.2.5 Phase sequence protection

By default, the L1L2L3 sequence is set as correct in UMC parameters. If we change the sequence by a connections swap of two phases and try to switch the panel on, the UMC will recognize it as a fault condition and trigger a trip with the fault message "Wrong phase sequence" on the LCD and will not allow starting the motor. In our case, It is detected even if the motor is switched off and the motor current is zero because the phase sequence is recognized by a voltage measurement with the VI155 device.

6.2.6 PTC protection

The PTC protection function of the UMC is simulated with the potentiometer R1 used as a rheostat, which is connected to the T1/T2 terminals of the UMC device (Figure 32). It is 2 Watt, 5 kΩ, ten turns potentiometer with a low TCR resistance wire. The thermal trip is achieved by a variation of the resistance at T1/T2 inputs which is executed by the rotation of the rheostat's rod.

According to [3], the PTC protection function of UMC has the following parameters:

Table 24 – PTC protection parameters[3].

Thermistor Motor Protection (PTC - binary) Type A	
Broken wire resistance Voltage at broken wires between terminals T1/T2	> 4.8 kΩ 12 V DC (typ.)
Response resistance	3.4 - 3.8 kΩ
Reset resistance	1.5 - 1.65 kΩ
Short circuit resistance Current at short circuit conditions	< 21 Ω 1.5 mA (typ.)
Response time	800 ms
Max. cold resistance of PTC sensor chain	< 1.5 kΩ
Line length	2.5 mm²: 2 x 250 m 1.5 mm²: 2 x 150 m 0.5 mm²: 2 x 50 m
Isolation	No

The resistance parameters of the thermal trip, PTC short-circuit, open-circuit conditions and reset value are tested by a simulation and checked by measuring the rheostat's resistance using the multimeter. At first, the fault condition is achieved by adjustment of rheostat's resistance and it is acknowledged by the UMC, then the rheostat is disconnected from the UMC and its resistance is measured. The results of fault trigger and reset resistances measurements are tabulated below.

Table 25 – UMC PTC protection functions testing.

Parameter	PTC trip resistance	Reset resistance	Open circuit resistance	Short circuit resistance
UMC fault message	"PTC temperature"	-	"PTC wire break"	"PTC short circuit"
Theoretical value	3.4-3.8 kΩ	1.5-1.65 kΩ	>4.8 kΩ	<21 Ω
Experiment 1	3.625 kΩ	1.573 kΩ	4.84 kΩ	22.9 Ω
Experiment 2	3.621 kΩ	1.571 kΩ	4.86 kΩ	22.6 Ω
Experiment 3	3.622 kΩ	1.565 kΩ	4.88 kΩ	22.1 Ω
Mean value:	**3.623 kΩ**	**1.570 kΩ**	**4.86 kΩ**	**22.53 Ω**

Conclusion

This diploma thesis was dedicated to the description and testing of the motor protection and control principles. In the beginning, the common and most frequent induction motor faults have been specified and their affection to the motor has been explained in order to define the most significant and important protection functions. Moreover, all general ways to start the motor have been mentioned and their impact on the electrical and mechanical quantities during motor start and continuous run has been shown to designate the necessity of these applications for various cases.

After specification of necessary protection and control functions for the motor, the UMC100 was selected as the device for research work and testing in this field of study. The main components and parts of the device have been specified. The operation principles of the main protection and control functions have been described, their parameters have been mentioned.

Then, the demo panel for testing and measurement of the UMC100 functions was built and parametrized. The demo panel contains following selected components: UMC device with expansion modules, motor, two contactors, VFD, two circuit breakers, rheostat, lamps, and switches for demonstrations of the panel functionality.

At the final stage tests and measurements of the panel were held. The following control functions were checked: forward/reverse start and stop, checkback, and fault behaviour for different cases. Also, the protection functions (long start, phase imbalance, phase loss, phase sequence, undervoltage, and thermal protections) were triggered and tested.

In this diploma thesis, the demo testing panel with UMC100 has been represented as a complex comprehensive device that contains advanced motor protection, flexible motor control, diagnostics and maintenance data, customized parameters and signal monitoring.

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Annex A – Wiring diagram for the demo panel with a regulating rheostat (Appendix in IS EDISON)

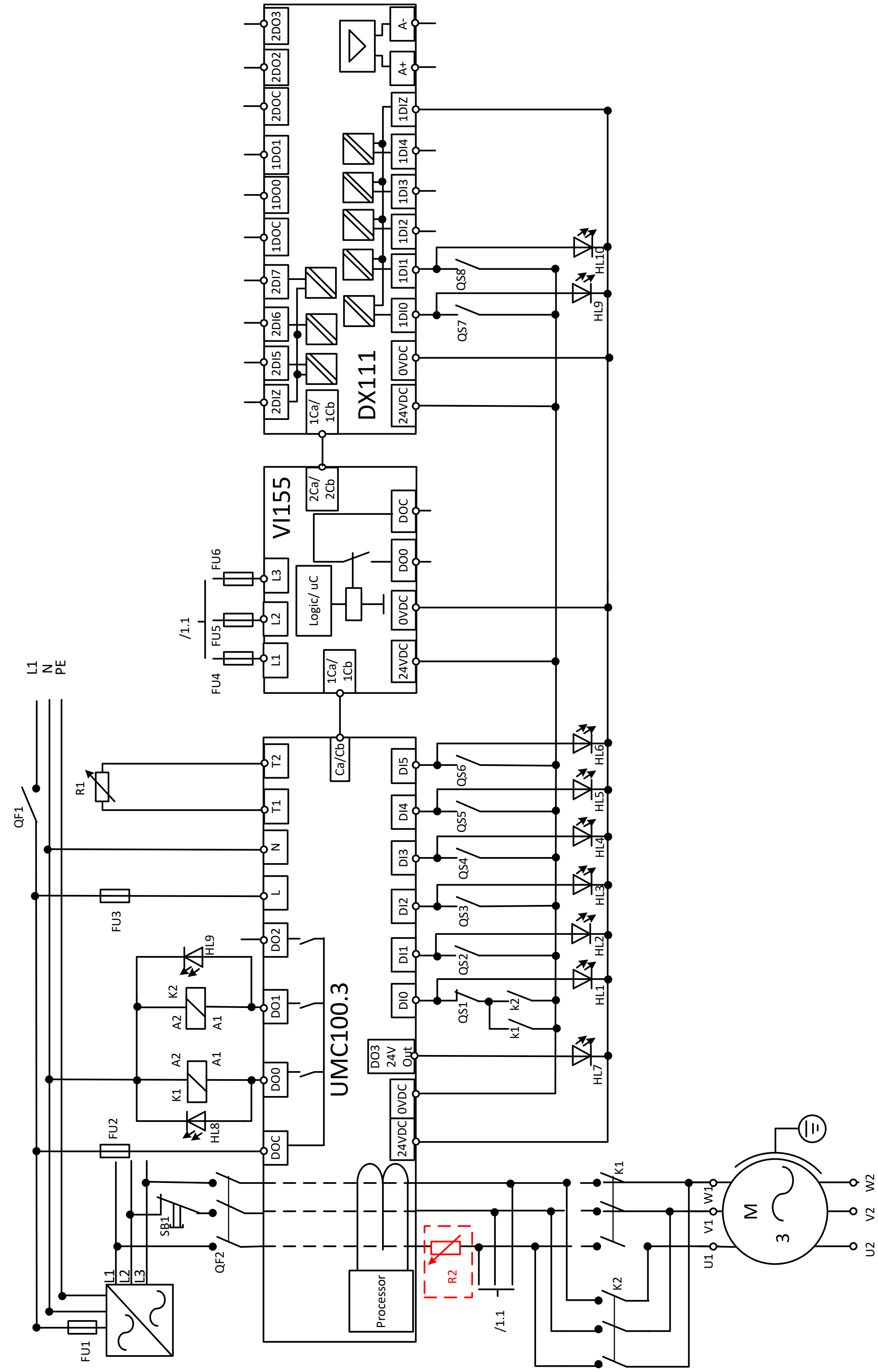

Figure A.1 – Wiring diagram for imbalance protection testing